JOURNAL OF THE AERONAUTICAL SCIENCES

VOLUME 7 APRIL, 1940 NUMBER 6

Some Economic Aspects of Transport Airplane Performance. Part I*

W. C. MENTZER AND HAL E. NOURSE

United Air Lines Transport Corporation

ABSTRACT

Total air transport operating costs are divided into three general classifications: (1) Significant operating costs which are defined as those resulting from the flight of an airplane or those affected by variation of airplane size, power, initial cost, and aerodynamic efficiency. Equations for the development of significant costs are presented. (2) Passenger service costs which are defined as those which vary with the number of passengers aboard an airplane are enumerated. (3) Overhead costs in air transportation are also dwelled upon and it is concluded that these costs change their proportion to significant costs when the physical and performance characteristics of the airplane being considered change.

The marked effect on significant cost of varying airplane utilization is brought out. Utilization is also shown to be chiefly a function of trip length, with block speed, seasonal schedule variation, and other factors being secondary functions.

The effect on significant cost of varying block speed either by increasing cruising power or improving aerodynamic efficiency is investigated for one type of transport airplane. Increased block speed obtained by increasing cruising power is found to increase significant cost very rapidly. Increased block speed obtained by improving aerodynamic efficiency is found to decrease significant cost appreciably and relatively large increases in airplane first cost are found to be justified if aerodynamic efficiency is improved. The adverse effect on significant cost of increasing trip length is investigated. The effect of changing specific fuel consumption is discussed.

It is pointed out that economic factors apart from those associated with fundamental airplane design and performance, such as interior arrangement, safety records, competition, and general economic conditions, play the major role in the economic outcome of air transportation.

Part I. Development of Significant Cost Equations

THE purpose of Part I of this study is to develop and explain the several cost equations which as a group comprise the significant cost of transport airplane operation as defined in the succeeding section, and to dwell briefly on the nature of overhead costs.

SIGNIFICANT OR DIRECT COST EQUATIONS

Significant or direct costs may be defined as those costs resulting from the flight of an airplane and those costs affected by airplane size, power, initial cost, as well as aerodynamic efficiency.

After a study of the operating and economic characteristics of two known types of airplanes, a series of operating cost equations has been devised taking into consideration most of the pertinent and influencing cost factors. These equations are used in the determination of significant costs of operation of the transport airplanes investigated in Part II of this study.

It is difficult and probably impossible to state in equation form a series of "fool proof" factors which will measure or project significant costs accurately and universally on all types of air transport airplanes known or on the horizon of the future. In the first place, maintenance and overhaul costs vary from year to year on the same equipment within the same company. The practices of the major companies are likely to be different from those of smaller feeder line organizations. For one thing, elaborate overhaul and repair depots are not economical until the volume of operation is considerable. Also complication of structure, including supercharged cabins, interior arrangements, etc., which affect first cost, depreciation, and maintenance, are

Presented at the Airplane Design Session, Eighth Annual Meeting, I.Ae.S., New York, January 26, 1940.

* Part II, on "Airplane Characteristics in Terms of Significant Operating Cost," and Part III, on "Economic Factors Not Associated with Design and Performance," will appear in the May issue.

likely to differ on large transport airplanes compared to smaller ones. These and other contingencies of similar nature make it difficult to express costs in a universal manner.

There is offered, however, immediately following a series of significant operating cost equations with sufficient explanation attending each equation for its understanding. Each of these equations is given first in general terms and then with the specific constants assumed in this study inserted. All equations are expressed in terms of cost per ton mile of payload capacity which is considered the significant cost.

Symbols

V_b	= Block speed	m.p.h.
L	= Payload	tons
N	= Number of engines	
M	= Number of seats	
P	= Total cruising b.hp.	hp.
U	= Utilization per year per airplane	hr./yr.
C_t	= Total cost of airplane and engines	dollars
C_a	= Cost of airplane less engines	dollars
C_e	= Cost of one engine	dollars
W_a	= Weight of airplane less engines	lb.
W_e	= Weight of one engine	lb.
Y	= Number of cylinders per engine	
C_m	= Cost per ton mile of payload capacity	dollars

The subscript "zero" added to any of the above symbols indicates that the value is known and therefore must be taken from transport airplanes whose economic characteristics are known.

Fuel Cost Including Tax

$$C_m = \frac{(\text{Fuel Cost in dollars per gal.})\ (\text{Cruise Sp. Cons.})P}{6V_bL} \tag{1}$$

$$= (0.127)\ (0.45)\ P/6V_bL$$

The determination of fuel cost is simple and straightforward unless extremely accurate results are desired in which event it is necessary to consider individually the additional fuel used for engine run-up, taxiing, take-off, and climb. However, the use of block speed instead of level flight speed in the above equation gives a very close approximation to true fuel costs.

It is estimated 90 octane fuel would be obtainable on a volume contract basis at prices ranging from \$0.10 to \$0.145 per gallon (including tax) according to freight rates and location of airport of delivery in United States. For the purpose of this study an average price including tax of \$0.127 per gallon is used.

The specific fuel consumption of 0.45 lb. per b.hp. hr. used above is approximately the best that can be obtained with late type engines when operated in the neighborhood of 50 percent of take-off power.

Oil Cost Including Tax

$$C_m = \frac{(\text{Oil Cost in dollars per gal.})\ (\text{Cruise Sp. Cons.})P}{7.5V_bL} \tag{2}$$

$$= (0.4)\ (0.012)P/7.5V_bL$$

A major air transport operator will be able to negotiate oil contracts which will deliver oil to airports over a large geographical area at a cost including Federal tax from \$0.35 to \$0.45 per gallon. For the purpose of this study, the average cost of oil per gallon including tax is assumed to be \$0.40.

A standard practice of operators is to drain engines of all oil at periodic intervals measured in terms of engine running hours. A reasonable estimate of this draining loss has been found to be 20 percent of the oil actually burned.

The approximate cruising specific consumption for engines of known characteristics is 0.01 lb. per b.hp. hr. Hence, the equation above uses a specific oil consumption of 0.012 which includes the additional 20 percent.

Airplane Depreciation Cost

$$C_m = \frac{(C_a - \text{Salvage})}{C_a} \times \frac{C_a}{(\text{Depreciation Period in years})\ UV_bL} \tag{3}$$

$$= 0.90C_a/6UV_bL$$

Air transport accounting practice in general calls for a straight line depreciation method for airplanes after a salvage or residual sum has been taken from the first cost. The above equation assumes this straight line method over a period of six years with a salvage value of 10 percent of original cost. Original cost entering into the depreciation problem is taken as the cost of the airplane complete including propellers, instruments, and radio, but less engines.

How to handle propeller depreciation raised a question, for a propeller is divided into two main parts differing in length of life. It has been found that an airplane will wear out perhaps three sets of blades but the hub will remain in use during almost the entire life of the airplane. In other words, the hubs approximate airplane life and the blades engine life. The propellers were considered part of the airplane for two reasons: (1) for purposes of simplification; and (2) because this practice has been and still is followed by air transport accounting departments.

Engine Depreciation Cost

$$C_m = NC_e/(\text{Engine Life in hours})\ V_bL \tag{4}$$

$$= 4C_e/5000V_bL$$

Air transport accounting practices generally accept engine running hours as a basis for depreciation and

therefore hourly engine depreciation is simply the engine first cost divided by the engine life in hours.

No allowance for salvage value is placed in the equation above although experience dictates allowance should be made if hours of life are estimated to be less than 5000. Such salvage inclusion could be made in the same manner as shown in the airplane depreciation equation.

Large operators usually purchase engines in fair-sized groups, and there is now a rapidly growing school of thought within the air transport industry which proposes that engine costs be grouped and depreciated on a straight line calendar year basis similar to the method used to depreciate airplane costs. From an operations and maintenance view, however, it will probably always be necessary to keep individual engine time.

Airplane Overhaul and Repair Cost

$$C_m = \frac{\text{Labor} \times \left(\frac{M}{M_0} + \frac{N}{N_0}\right) + \text{Material} \times \left(\frac{W_a}{W_{a_0}} + \frac{C_a}{C_{a_0}}\right)}{2V_bL} \tag{5}$$

$$= \frac{2.48\left(\frac{M}{21} + \frac{N}{2}\right) + 2.00\left(\frac{W_a}{13{,}800} + \frac{C_a}{100{,}000}\right)}{2V_bL}$$

Airplane overhaul and repair cost characteristics on two types of airplanes were known by the authors. By inspection of these characteristics important relationships were determined as to the material and labor functions of overhaul and repair.

Cost per hour flown of labor and material are represented by \$2.48 and \$2.00, respectively, taken from experience concerning a particular type of airplane. The 21, 2, 13,800 and 100,000 indicate, respectively, number of seats, number of engines, weight empty less engines, and cost in dollars of the airplane whose overhaul and repair costs are as stated above. Interior complications and arrangement expressed as seats, M, and engine change expressed as number of engines, N, in the equation, are important functions of labor costs. Airplane weight empty less engines, W_a, and airplane cost less engines, C_a, are important functions of material costs. Each function appearing in the equation is given one-half weight; hence the 2 in the denominator.

There are other airplane overhaul and repair costs which usually appear as such, not included in the above equation. These are the cost of special airplane revisions or projects not capitalized, and purchase and installation of deicer boots. Such costs might increase the routine costs covered by the equation by between 10 percent and 25 percent, but they are omitted from direct costs in this study and considered as being a part of overhead costs.

Engine Overhaul and Repair Cost

$$C_m = \frac{\frac{N}{N_0}\left[\text{Labor} \times \left(\frac{W_e}{W_{e_0}} + \frac{Y}{Y_0}\right) + \text{Material} \times \left(\frac{W_e}{W_{e_0}} + \frac{C_e}{C_{e_0}}\right)\right]}{2V_bL}$$

$$= \frac{\frac{N}{2}\left[1.0\left(\frac{W_e}{1400} + \frac{Y}{14}\right) + 2.25\left(\frac{W_e}{1400} + \frac{C_e}{12{,}000}\right)\right]}{2V_bL} \tag{6}$$

As was the case with airplane overhaul and repair, overhaul cost characteristics for engines were known for two types of engines. Important relationships here were also established between costs and labor and costs and material.

Known labor and material costs are represented by \$1.00 and \$2.25, respectively, per airplane hour flown. The 1400, 14, and 12,000 indicate, respectively, engine weight, number of cylinders per engine, and unit cost of engines whose overhaul and repair costs are as stated above. Engine weight, W_e, and number of cylinders, Y, are found to be important considerations in determining labor costs, whereas weight, W_e, and first cost, C_e, are important functions of overhaul material costs. Inasmuch as the known labor and material costs are on an airplane hour basis for an airplane having two engines, this whole section is bracketed and multiplied by the ratio $N/2$ to make the equation applicable to an airplane having a different number of engines.

As in the case of airplane overhaul and repair, each function is given one-half weight in the equation; hence the 2 in the denominator.

Airplane and Engine Ground Service Cost

$$C_m = (\text{Labor} + \text{Supplies})\left(\frac{2N}{N_0} + \frac{W_a}{W_{a_0}}\right) \Big/ 3V_bL \tag{7}$$

$$= 5.50\left(\frac{2N}{2} + \frac{W_a}{13{,}800}\right) \Big/ V_bL$$

Airplane and engine ground service cost as expressed in the above equation includes the labor cost for cleaning and washing the airplanes both outside and in, checking engines, and checking airplane structure periodically. It also includes the cost of some cargo-loading labor. Supply costs include cost of grease, waste, cleaning compounds, perishable tools, etc.

Before further explaining the above equation, it might be well to dwell briefly on the basic nature of this type of cost. It is an uncertain cost and is difficult to associate with any particular airplane characteristic such as weight or power. Operations men are not sure of the reasons for fluctuations of airplane service costs and hesitate to predict what a fleet of large four-motored craft might require in the way of service. The irregular service costs with regard to the operation

of two known types of airplanes indicate that the skepticism of operations and line service experts contacted is well founded.

Some engaged in airplane economic studies have ignored it as a significant cost and considered it as overhead. For the purpose of this study, however, an equation is offered which at least clings to a cost base drawn from experience. The \$5.50 in the equation represents the service cost per airplane hour flown for a known airplane and operation. The cost of airplane service is assumed to vary with the number of engines, N, and the weight of the airplane empty, W_e. Inasmuch as the engines require frequent oil, grease, and electrical service, the engine function expressed as $2N/N_0$ is given twice the weight given to the airplane weight function; hence the 3 in the denominator.

Crew Pay and Insurance Cost

First Pilots

$$C_m = (1 + \text{Ins. Rate}) \left[(\text{Day-Night Factor})(3.55 + 0.00667 V_b) + (\text{dollars per mi.})(V_b - 100) + \frac{\text{Annual Base Pay}}{\text{Annual Flying Hours}} \right] \Big/ V_b L \quad (8)$$

$$= 1.07 \left[1.25\,(3.55 + 0.00667 V_b) + 0.01\,(Vb - 100) + \frac{2400}{850} \right] \Big/ V_b L$$

Other Crew Members

$$C_m = (1 + \text{Ins. Rate}) \left(\frac{\text{Annual Pay at } V_{b_0}}{\text{Annual Flying Hours}} \right) \times \left(\frac{1 + V_b/V_{b_0}}{2} \right) \Big/ V_b L \quad (9)$$

$$= 1.07 \left(\frac{3700 + 2400}{850} + \frac{1620 + 1420}{900} \right) \times \left(1 + \frac{V_b/160}{2} \right) \Big/ V_b L$$

Insurance Portion of Equation

It is reasonable to assume that a major air transport operator would carry the following insurance on its flight crew: (1) Compensation Insurance, (2) Group Life Insurance, and (3) Federal Old Age Benefits and Unemployment Insurance.

After a study of insurance as related to flight payroll costs, it is estimated that the cost of the above insurance will approximate 7 percent of total flight payroll costs.

First Pilot's Pay

Pilots in charge of transport airplanes are paid in accordance with a scale as set down in ruling No. 83 of the Federal Labor Board. It is composed of three portions: a base or fixed pay; an hourly rate; and a mileage differential. The above equation considers all three portions.

The hourly rate is dual, one for day flying and one for night flying. The night rate is always 50 percent greater than the day rate; hence the factor 1.25 in the equation which assumes a half day and half night operation. The expression $(3.55 + 0.00667 V_b)$ covers the hourly rate in terms of block speed as illustrated in Fig. 1.

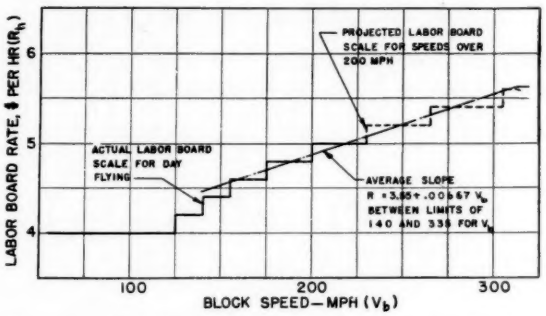

FIG. 1. Labor Board rate of hourly pay for first pilots as affected by block speed.

The Labor Board scale of pay takes cognizance of speeds up to only 200 m.p.h. It is necessary therefore to extrapolate the curve in Fig. 1 to speeds well beyond the Labor Board limit in order to provide an hourly pay basis for the airplanes compared in this study.

The pilot's pay mileage differential for airplanes of the velocity investigated in this paper will automatically allow \$0.01 per mile for all miles above 100 flown during each hour. This relationship can be expressed as $0.01(V_b - 100)$.

Pilot's base pay was fixed at \$2400 per annum for 850 hours of flying time.

The Labor Board plan for pilots' pay is the result of a compromise between the Airline Pilots' Association and company management. It is an attempt to divide the theoretical economy in pilots' pay derived from additional airplane speed between the pilots and the company involved.

Other Crew Members' Pay

The equation on pay for other crew members takes cognizance of the compromise mentioned above when airplane speeds are increased markedly and it assumes the company could gain only one-half of the theoretical economy on crew pay as airplane speeds increased in the future.

The expression (Annual Pay at V_{b_0}) indicates about the present average annual pay of second pilots and stewardesses at present average block speeds of 160 m.p.h. or $3700 and $1620, respectively. Flight engineers and cabin boys are assumed to receive $2400 and $1420 flat annual pay for present block speeds. The cockpit crew is assumed to work 850 flying hours and the cabin crew 900 flying hours annually.

In the expression $(1 + V_b/160)/2$, 160 represents present block speed in m.p.h. on the United Air Lines system and the formula is designed to allow one-half of the theoretical economy provided by increased airplane speed.

Crew Expense

Cockpit Crew

$$C_m = (\text{Per Mile Cost})(\text{Crew Members})/L$$
$$= 0.00225\ (\text{Crew Members})/L \qquad (10)$$

Cabin Crew

$$C_m = (\text{Per Mile Cost})(\text{Crew Members})/L \qquad (11)$$
$$= 0.00344\ (\text{Crew Members})/L$$

This cost includes allowances to the airplane crew for hotel bills and meals when away from point of domicile, moving expenses involving transfers of personnel, and rent, bedding and linen, etc., of stewardess' apartments. The 0.00225 and 0.00344 are in terms of dollars per mile taken from actual operating experience.

Airplane Public Liability and Property Damage Insurance Cost

$$C_m = \text{Rate per mile}/L \qquad (12)$$
$$= 0.0013/L$$

This type of insurance is quoted by insurance underwriters on a per mile flown basis and it is known that such insurance coverage might be purchased at rates from $0.0011 to $0.0014 per mile flown. An average rate of $0.0013 is used above.

Interest on Investment

$$C_m = \frac{(\text{Average Investment}/C_l)(\text{Interest Rate})C_l}{UV_bL} \qquad (13)$$
$$= (0.7)(0.04)C_l/UV_bL$$

Average investment is considered to be 0.7 of money originally invested, and interest lost due to money invested is assumed at the rate of 4 percent.

Airplane Accident Insurance (Crash, Fire, Wind) Cost

$$C_m = \left(\frac{\text{Insured Value}}{C_l}\right)\left[\frac{(\text{Rate per dollar valuation})C_l}{UV_bL}\right] \qquad (14)$$
$$= (0.9)(0.08)C_l/UV_bL$$

During the past four years an approximate check reveals that major domestic transport operators' losses from crash have amounted to less than 4 percent of original fleet values. It is known that insurance underwriters have quoted in the recent past crash insurance rates ranging from 5 percent to $7\frac{1}{2}$ percent of insured values according to the individual company's accident records.

Crash insurance purchased in the open market for expensive four-engined aircraft would likely be high at first because of the tremendous risk tied up in a single airplane and therefore the desire on the part of the insurance company to accumulate a fund of money quickly from which to meet contingencies.

Fire and extended coverage insurance can be purchased for large transport airplanes of today at prices ranging from $0.0160 and $0.0230 per dollar of insured value per year. For purposes of this paper, the figure $0.08 for all airplane accident insurance has been used.

Insured value may not always be equivalent to original cost depending on the state of obsolescence of the airplane and whether or not it would be replaced if destroyed. The preceding equation assumes an average insured value over the life of the airplane of 0.9 of original cost.

Costs That Change with Passenger Volume

The operating costs that move with volume of passengers are not considered a part of significant cost. Although most of these costs are generally considered direct operating in nature they are dependent primarily on the number of passengers aboard and will remain fairly constant per passenger regardless of equipment operated.

The following list sets forth those cost classifications considered to be closely associated with passenger volume:

(1) Telephone and telegraph, reservations, (2) Passenger liability insurance, (3) Food and food supplies, (4) Commissions paid to agents for ticket sales, (5) Cost of passenger ticket stock and other passenger supplies.

Experience indicates the above classifications will total about $0.005 per mile per pay passenger aboard an airplane. This unit figure is more applicable to a transcontinental service and the figure for feeder line service will undoubtedly be smaller. A simple equation to obtain this cost is:

$$\text{Passenger Service Cost in dollars per mile} = 0.005\ (\text{Number Passengers aboard}) \qquad (15)$$

Airplane Utilization

General

Utilization per year per airplane represented in the cost equations of this study by "U" has such an important bearing on total significant cost that a short section of this paper devoted to its treatment is felt justified.

Airplane utilization is determined by the following factors:

(1) The type of work the airplane has to do.
  (*a*) Coast to coast sleeper service.
  (*b*) Short or medium haul frequency service.
  (*c*) Local, terminal or feeder service.
(2) Amount of error entering into projection of business prior to fleet purchase.
(3) Seasonal fluctuation of scheduled mileage.
(4) Time lost because of overhaul, unexpected contingencies, and protection of service with spare airplanes.

Before an airplane or group of airplanes is purchased by an air transport company, the work that the airplane will have to do, the amount of business expected, and peak period requirements to satisfy the expected business demand are carefully worked out. The specific work the fleet will have to do is the greatest single factor in predetermining the general bracket of utilization within which the airplanes will fall. Errors in judgment as to the amount of passenger business that might be available prior to fleet purchase and/or seasonal schedule fluctuation will affect utilization one way or another within the "job bracket." Usually a major operator will try to provide cargo space and seats to satisfy in excess of 95 percent of business offering over the peak summer period lasting from June through October. If the nature of the operation is highly seasonal, there are likely to be airplanes not utilized to a great extent during the winter months.

It is quite obvious that the airplane used in transcontinental sleeper service will always have the highest utilization factor. The airplane used in feeder or local service will show in general the lowest utilization and the airplane used to provide frequency of service between thickly populated areas such as Boston–New York, New York–Chicago will attain an in-between utilization goal.

This Study

If it became practicable or possible to use a fleet of airplanes of a given type in transcontinental service alone, each operating coast-to-coast daily, an overall utilization in excess of 810,000 miles per year per airplane might be consummated. This is over 4000 hours per year at a block speed of 200 m.p.h. Unfortunately this probably would not be the case if a fleet of airplanes of the general type being compared in this study were operated by a transcontinental carrier. Such a fleet would probably divide most of its flight time in transcontinental and local Chicago–New York or other similar local service.

For the purpose of this study the utilization has been planned on a mileage basis with the assumption that the airplanes investigated would be operated transcontinentally three round trips per day as well as New York and Chicago with two round trips daily in addition to the transcontinental operation. Immediately below is Table 1 setting forth the mileage calculations on an annual basis and airplanes utilized for this service.

Table 1

Mileage Calculations on an Annual Basis and Airplanes Utilized

Schedules	Miles	Airplanes
3 Round Trips Coast-to-Coast	5,694,000	6
2 Round Trips Chicago–New York	1,095,000	2
Reserve Airplane		1
	6,789,000*	9

* Ferry and test mileage assumed to offset miles cancelled.

The equation for utilization as used in Eqs. (3), (13), and (14) becomes

$$U = \frac{6{,}789{,}000}{9V_b} = \frac{7.54}{V_b} \times 10^5 \qquad (16)$$

Table 1 makes no allowance for curtailment of scheduled service in the winter. Also a minimum of spare equipment is planned; there is virtually none for schedule protection, and it is considered that most overhaul and repair as well as engine change work will be accomplished at tide water terminals during the daytime between transcontinental sleeper schedule arrivals and departures. Due to equipment size and schedule frequency planned, no airplanes are provided for extra sections. In short, the utilization of mileage as set up in Table 1 approaches the ideal for present-day transcontinental operators.

Utilization Largely a Function of Trip Length

For most schedule setups, as the block speed of an airplane increases, its hourly utilization is affected inversely. This paradox is best illustrated by transcontinental sleeper schedules. An airplane barely able to make a coast-to-coast trip with reasonable time at its termini for service before the return trip will attain higher utilization than the airplane which is capable of flying the same route in less than half the twenty-four-hour period. After reaching tide water and after an adequate service period, neither airplane could be counted on for additional flight service without jeopardizing the return transcontinental departure time.

This would be especially true if overhaul work were performed during the day. Utilization is limited further by trip length as the length of the trip is shortened. This situation will prevail generally until block speeds of airplanes are doubled compared to present speeds.

Speed Requirements

If additional speed is not required for service of local nature, the maximum speed necessary in domestic operation might be determined by a block speed fast enough to fly an overnight coast-to-coast eastbound schedule. If cargo and passengers could leave the west coast at the close of a business day, the passengers go to bed on the airplane and arrive at their destination on the Atlantic seaboard at the start of the next business day, there really would be no occasion for greater speed.

Present airplanes approach this goal on westbound trips because the time belt changes are in the airplanes' favor. Transport airplanes now leave the east coast at about 5.00 p.m. Eastern Standard Time and arrive on the west coast about 9.20 a.m. Pacific Coast Time. Eastbound of course, the opposite is true, and the speed of the airplane must overcome time-belt changes if an overnight flight is to be accomplished. This time-belt handicap on eastbound flights is partially overcome by prevailing winds which blow from west to east and usually help an airplane flying in this direction.

If a transcontinental overnight service is assumed eastbound with a 15 m.p.h. tail wind, the pertinent factors regarding such a schedule are set forth in Table 2 below.

TABLE 2

Factors for Eastbound Transcontinental Overnight Service

		Stops			
			Ground		Cruise Speed
Leave	Arrive	No.	Time	V_b	Still Air
6:00 p.	8:00 a.	2	30 min.	260 m.p.h.	273 m.p.h.
6:00 p.	8:00 a.	3	20 min.	260 m.p.h.	281 m.p.h.

The above schedule approaches an ideal for eastbound service and an airplane with a block speed 30 m.p.h. slower might still be satisfactory on eastbound overnight flights. Westbound, the same airplane as illustrated in Table 2 might leave the east coast late enough to allow the passenger to have eight o'clock dinner at home and leisurely arrive at the airport to connect with a schedule due on the west coast at the beginning of the next business day.

Effect of Utilization on Cost

According to the cost equations set forth in this study, airplane utilization will affect the following significant costs: (1) airplane depreciation, (2) airplane accident insurance, and (3) interest on investment.

Fig. 2 illustrates the profound influence of airplane utilization on significant cost as outlined in this study.

It will be noted from Fig. 2 that direct costs per mile flown may be made to fluctuate as much as 8 cents between the limits of utilization of 2200 and 3720 hours per annum. An airplane used entirely for short or

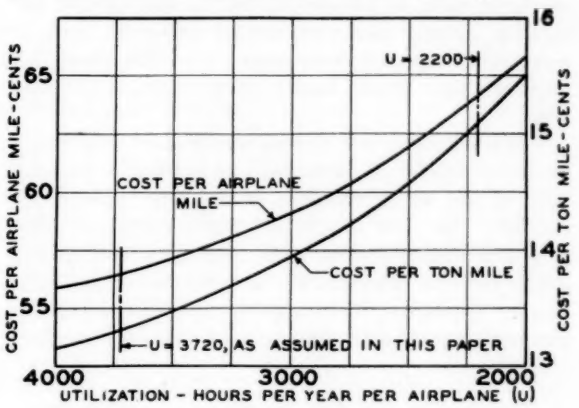

FIG. 2. Significant costs as affected by utilization for airplane later described as f = 35 sq. ft. 600 mile range, block speed of 202 m.p.h.

medium haul frequency of service might well only be utilized 2700 hours per year or less whereas, as previously explained, if the same airplane were engaged chiefly in transcontinental service, its utilization might be 3700 hours or more per year.

OVERHEAD COSTS

Total air transportation operating costs have been found to be divided into three general groups (two of which have already been explained) as follows: (1) significant costs, (2) passenger volume costs, and (3) overhead costs.

There have been many theories expounded as to the allocation of overhead costs to direct operating costs. It is a perplexing problem because the allocations are affected by so many variables such as utilization of flying equipment, size of flying equipment, as well as the difference in fundamental nature of a host of overhead cost classifications. The perplexity is also increased when the problem of allocation is considered for an air transport line which uses more than one type of flying equipment in its day-to-day operation. At best, it appears that the treatment of overhead will always be more arbitrary than the treatment of significant costs.

If a straight weight carrying allocation basis is used, then the more efficient airplane takes a cost penalty for its increased efficiency compared to the one with less efficient weight ratios.

Some operators maintain that overhead should be allocated on the basis of "ability to pay." With this system the airplane which is a passenger and cargo getter will bear the brunt of the overhead load, and

the airplane less popular or one which is necessary to satisfy the minimum demand of public convenience and necessity perhaps, assumes the lesser overhead burden.

There is no question but that a sprinkling of large airplanes, such as described in this study, within a fleet of smaller airplanes will tend to increase such overhead costs as property taxes, certain ground insurance, ground passenger service personnel, hangar rents, certain ground depreciation, etc. Therefore, the larger airplane should bear a greater portion of overhead.

When the many cost classifications which as a group constitute the overhead load are examined, it is found that all are not a function of the same base. For example, the cost of ground flight personnel (dispatchers, meteorologists, radio operators, and clerks) might best be allocated on a schedule or per mile basis; passenger and cargo getting cost, including passenger agents and reservations personnel as well as promotional activity, might well be allocated on the basis of revenue load, or dollars of revenue.

It is reasonable to assume that hangar rentals, depreciation of ground servicing and housing facilities and fees for the use of landing areas are more closely associated with airplane weight than any of the aforementioned allocation bases. In other words it would seem that the allocation of overhead should depend on a series of equations (as with significant costs) covering the several avenues of overhead spending, each equation being dependent upon the association with or function of the cost considered. It is not believed reasonable to assume that overhead is directly proportional to significant cost regardless of the type of flying equipment or service being considered.

Inasmuch as this paper has for its principal purpose the economic aspects of airplane performance, no attempt has been made to work out detailed equations for the distribution of overhead.

Book Review

Mathematical Methods in Engineering, by TH. V. KÁRMÁN and M. A. BIOT; McGraw-Hill Book Co., 1940. 500 pages, $4.00.

Books on mathematics written by mathematicians almost invariably deal with methods of solution of purely mathematical problems, but they hardly ever touch upon the subject of the formulation of a mathematical problem out of a physical situation. This process, however, is often more difficult than that of mathematical solution, and for some time a widely-felt need has existed for a book giving sufficient attention to this phase of the subject. In the last decade a number of books on engineering mathematics have appeared that have attempted to fill this demand, with varying degrees of success, but it appears that the present book fulfills the ideal almost completely. It is very well written, refreshing in spirit, clear in style and language, well illustrated and printed, and contains a large number of problems. More than half of its pages are devoted to the transformation of the problems of engineering and physics to a mathematical form. Also the various methods of solving mathematical problems are always illustrated on some definite question in engineering or physics. The subjects treated are those that are of interest to engineers and physicists, while material of great importance to mathematicians, but seldom used by engineers, is left out. However, even within this limitation, the book is not complete. The important subjects of conformal mapping and complex integration, partial differential equations, and integral equations are not treated. It is understood that the authors are working on a second volume to contain these subjects and some others and, in view of the excellence of the present volume, it is to be hoped that its companion will be published in the not-too-distant future.

The book consists of eleven chapters, the first of which contains a review of the calculus and the *useful* ordinary differential equations. Most of the space is devoted to linear equations with constant coefficients, while legendary equations such as the one of Clairaut, which appear in all mathematics books but never in life, are conspicuously absent. Methods of numerical integration of the equations are stressed, and in general the whole presentation is very clear and graphic.

The rather short second chapter deals with Bessel functions and gives a table listing the comparative notations of various authors. It seems that almost every writer on these functions has his own notation and a study of the literature on the subject is eased considerably by this table, which enables the reader to translate from one symbolism to another.

The third chapter is entitled "Fundamental Concepts of Dynamics," and gives just what the title implies, a nice and concise review of that subject, including the gyroscope and Lagrange's equations. Another very appropriate name for this section might have been "Vector Analysis and Its Applications." This chapter is a particularly happy example of the authors' method of using an engineering question as a vehicle for the exposition of a mathematical subject.

Chapter IV, treating of "Elementary Problems in Dynamics," in a similar manner uses the simple pendulum to take a flyer in elliptic functions, while the motion of an airplane gives a fine opportunity to show the properties of singular points in differential equations. In the next chapter on "Small Oscillations of Conservative Systems," vibrating systems without damping are discussed and, incidentally, the authors give the theory of orthogonal functions and numerical methods for solving algebraic equations with real roots. The comparatively unfamiliar theory of matrices, which has appeared off and on in the literature of electrical and mechanical engineering during the last few years, is expounded in connection with the question of finding the natural frequencies of systems with many degrees of freedom. Mention is made of the interesting connection that exists between the matrix method and the process of successive approximations originated by Stodola.

Chapter VI on "Small Oscillations of Non-Conservative Sys tems" deals with vibrating systems with damping, either positive or negative. The section on the flutter of wings with ailerons is particularly interesting and simple. Several numerical methods for solving algebraic equations with complex roots as well as the Routh stability criteria of frequency equations need no excuse to be introduced at this point. Other subjects discussed in the chapter are vibration dampers and the longitudinal stability of airplanes.

Chapter VII bears the title "The Differential Equations of the Theory of Structures." It deals with deflections of structures, the shapes and frequencies of vibrating beams, and the closely related problem of buckling of beams. After this a general theory is given of iteration methods for finding the characteristic

(Continued on page 251)

Studies of High Speed Airplanes

FREDRIC FLADER AND E. RUSHMORE CHILD

Curtiss Aeroplane Division, Curtiss Wright Corporation

ABSTRACT

The authors have devised a series of high speed design studies in which several advanced ideas and innovations are proposed. The factors having an important influence on high speed are considered and the airplane design arrangements are so proportioned as to minimize adverse effects, to the lowest values which are believed attainable without fundamental changes involving the invention of new principles of flight now unknown or undeveloped.

Data are presented showing the lowest values of the drag of the component parts of a modern airplane, which represent current practices. Further data are given to show possible improvement in these values and the ones that may be entirely eliminated. An analysis of the factors influencing propeller design for high speed aircraft is made, together with a prediction of the propulsive efficiencies which may be obtained, based on recent research. The maximum attainable efficiency becomes less as the speed and altitude are increased. Possibilities of increasing the indicated optimum propulsive efficiencies and the desirability of a variable gear drive device, are discussed briefly.

The paper concludes with the familiar presentation of a chart showing the advance in high speed by years, which is extrapolated on the basis of the authors' studies to show a prediction of the maximum speed attainable with aircraft designed according to conventional practices. This maximum speed is considered attainable within two years.

THE authors have prepared this paper and present it from the point of view of the practicing designer and aerodynamicist. The contents represent studies of airplanes made in the manner employed in design offices, making use of the results of the authors' work with wind tunnel and flight tests.

Rather than approach the subject in general terms or by a mathematical development it was decided to explore the high speed possibilities of the future by a study of an airplane design, with some systematic variations of gross weight, wing loading, and power. The prerequisites for maximum speed are well established and most of the factors have been discussed by other authors.[1,3] The factors used as a basis for the present design studies are (1) high wing loading; (2) entirely enclosed power plant; (3) selection of optimum propeller, arranged as a pusher; (4) mid-wing and tail arrangement with elimination of unfavorable interference; (5) a cabin and windshield enclosed within the normal contour lines of the fuselage; (6) a finely streamlined fuselage shape; (7) smooth body, wing, and tail surfaces with the suppression of all excrescences, wrinkles, rivet heads and skin laps; (8) elimination of exposed scoops external to the normal contour lines of the airplane; (9) elimination of exposed exhaust stacks; (10) entire elimination of drag due to an imperfectly retracted landing gear; (11) selection of an optimum critical altitude; (12) selection of best airfoil section for the design maximum speed.

These concepts result in a basic airplane design which has been designated Design A and shown on Fig. 1.

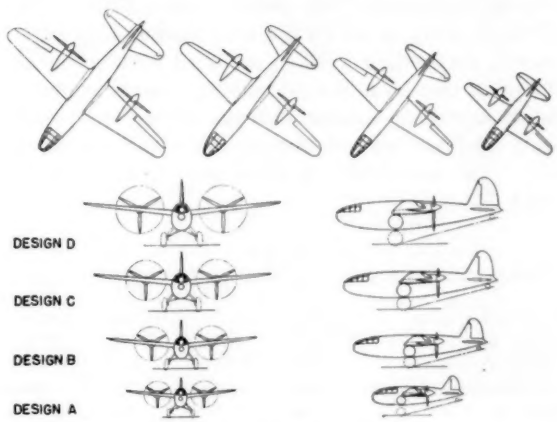

FIG. 1. Design studies.

This chart shows three other designs which have been developed for the purpose of surveying the effects of changes in size, power, and wing loading. One cannot draw conclusions with entire validity concerning these effects by means of generalized equations and charts. It is necessary by means of correct design proportions to take into account important considerations which the generalized approach neglects. It is for this reason that actual design layouts have been made in order to include the effects of space requirements for housing the pilot, the engines, cooling system, fuel and oil tanks, and the landing gear; and the effects of the proportioning of the length of the fuselage, tail surface areas, and other design factors which have important effects on performance.

In these designs all emphasis has been placed on speed. The engine power selected for each design is based on available liquid cooled engines. Design A has a single engine. The remaining designs are two engined airplanes.

The specifications of the four similar design studies shown by Fig. 1 are given in Table 1.

Presented at the Aerodynamics Session, Eighth Annual Meeting, I.Ae.S., New York, January 26, 1940.

TABLE 1

	A	B	C	D
Gross Weight, lb.	6000	11200	15800	20600
Power, hp.	1150	2300	3450	4600
Wing Area, sq.ft.	110	207	293	382
Tail Surface Area, sq.ft.	39	73	104	136
Span, ft.	28.3	38.75	46.2	52.7
Length, ft.	22.5	33.75	39.3	43.3
Wing Loading	54	54	54	54
Stalling Speed, m.p.h.	84	84	84	84
Maximum Speed, m.p.h.	482	496	510	520

A variation to this series has been investigated in which the Design A is retained as the basic design, and the landing speeds of the remaining three are increased in proportion to the sixth root of the gross weight.[2] The first series has been proportioned on the basis of equal landing speeds. This requirement seems necessary if the landing distance over an obstacle is to remain constant regardless of the design of the machine. The following series in which the wing loading and consequently the landing speed go up, is set forth on the assumption that an unlimited landing space is available. Safety in making contact with the ground and negotiating small surface irregularities is the only consideration. The particulars of these designs are given in Table 2.

TABLE 2

	A	A-1	B-1	C-1
Gross Weight, lb.	6000	11200	15800	20600
Power, hp.	1150	2300	3450	4600
Wing Area, sq. ft.	110	167.5	211	252
Tail Surface Area, sq.ft.	39	59.5	75	89.5
Span, ft.	28.3	34.6	39.2	42.6
Length, ft.	22.5	31.9	36.3	38.4
Wing Loading	54	67	75	82
Stalling Speed, m.p.h.	84	93	99	103
Maximum Speed, m.p.h.	482	520	545	563

WING LOADING

Since the object of this paper is an investigation of maximum speed within the realm of possibility within the next few years, no consideration has been given to performance characteristics which ordinarily must receive attention, other than speed and the ability to take off and land safely. The stalling speeds given in Tables 1 and 2, although not moderate, are considered safe for a skilled pilot. Assuming the use of existing and proven devices for high maximum lift, a $C_{L_{max.}}$ of 3.0 has been selected and applies to all of the designs. This value has in fact been very nearly attained in machines now flying. This, combined with the selection of as high values for the stalling speed as are considered practical, result in very high wing loads, consequently low wing and tail areas, and small fuselage lengths. The resultant suppression of exposed surface or wetted area is an important factor in obtaining maximum speeds.

POWER PLANT

Insofar as immediate possibilities are concerned, a liquid cooled engine is considered best for maximum speed. The design studies have been built around known American engines, selected so that equal increments of power increase are obtained in the series. The engines are entirely enclosed and located centrally in each fuselage, with the pilot in a forward position. In each airplane of the series, twin pusher propellers are mounted behind the wing on either side of the fuselage. Transmission of power from the engines to the propellers is accomplished by the use of a remote drive arrangement. The transmission is so designed as to make a variable propeller drive speed possible. The improvement in propulsive efficiency at maximum power and low forward speed would be utilized to maintain reasonable distances for the take-off run and climb over an obstacle.

COOLING DRAG

The drag required to actually force air through the radiators which dissipate heat from the engine coolant and oil is only 3 or 4 percent of the total airplane drag. Additional drag associated with cooling, caused by getting the air to the coolers and out again, is large in proportion to the useful work done. In modern liquid cooled installations this, combined with the cooling drag, may be from 8 to 15 percent of the total. This large additional drag is usually due to the use of externally projecting louvres or scoops to catch the air, and to imperfectly shaped conduits or ducts, perhaps incorporating complicated and tortuous bends, to guide the air to the chosen location of the coolers; thence, after more power consuming changes in direction, the cooling air is discharged back into the external stream with additional disturbance to it. An air intake and duct system must be designed to admit enough air at low velocity to cool the engine on the ground and in take-off and climb at full power. Being so designed it will admit too much air at high speed, and consequently the engine will overcool unless the air flow is restricted for this condition. Restriction of the flow causes a spillage of the excess air over the edges of the entrance scoop. This spillage causes drag which may be termed the external drag of the duct system. The system also has internal drag measurable by the pressure drop through the conduit system. Friction on the walls of the ducts, opposition to easy flow around bends or over irregularities, and improper expansion account for this drag. A multiplicity of separate intake openings, say for cylinder cooling, oil cooling, carburetor air intake, accessory cooling, and cockpit ventilation, combine to create a large total drag, both internal and external. This drag may be considerably more than necessary, due to external interference between duct openings if they are located

close together, or to disturbance to the external air stream in several different regions if they are located separately.

The obvious way to reduce the total drag is to admit air into one opening only, then divide it internally into the several ducts leading to the points at which air is needed. The exit for the air should by preference be at the trailing end of a body, or at least must be carefully faired into the external stream. The single opening should be located at a stagnation point on the airplane, and so arranged as to cause as little disturbance as possible from spillage. An ideal location for this opening should be at the nose of the fuselage, which is the position chosen for all of these studies. A careful summing up of the intake loss and pressure losses in the ducts indicates that the duct system drag need not be more than $^2/_3$ of the cooling drag. The total cooling system drag should therefore be from 5 to 7 percent of the airplane drag.

Exhaust System

The ordinary exhaust system which shoots a stream of hot gases at right angles to the direction of flight or at a slightly backward angle is extremely detrimental. Projection of a column of gas in such a manner must create a large amount of turbulence, and hence loss in energy. The exhaust stacks themselves are very poorly streamlined bodies. This method of exhaust now causes a drag increment of $2^1/_2$ percent to 3 percent of the total. Well designed exhaust systems of the jet type found on some modern designs produce a drag as little as $1^1/_4$ percent of the total.

This drag may be entirely eliminated by exhausting the gases from the trailing end of the fuselage, an arrangement which is possible when the engine is mounted in the central part of the fuselage.

Aerodynamic Design

The general arrangement, with the pilot forward, permits the incorporation of the cabin and windshield within the normal contour of the fuselage. By using flush, transparent panel mountings, the drag of the ordinary windshield may be entirely eliminated. The forward pilot's position also allows the use of a mid-wing arrangement. A low drag fuselage using mathematically faired lines, together with the mid-wing position, is a favorable combination in which there should be no interference drag.

There are several items ordinarily existing in most airplanes which contribute unnecessary resistance. If a landing gear is to be made retractable, it should be so designed that it will be completely housed within the airplane, and a closely fitting cowl provided to seal off the openings. In this way, the landing gear drag may be eliminated or reduced to a negligible amount.

For best results, the most meticulous care must be taken to avoid non-useful flow of air into the airplane, or from the inside to the outside. Seals or bulkheads can usually be provided to avoid this condition, which often occurs around such parts as spinner, cabins, doors, and wheel openings. Flow through the space between main and control surfaces is to be avoided.

Aside from these considerations, it is, of course, necessary to so design the airplane that smooth exterior surfaces are obtained. Flush riveting or spot welding and flush skin laps are already the rule. The thin sheet-metal gages conventionally employed for covering are not easily laid smooth, and are subject to wrinkling under normal flight loads. The high and low areas from these causes have been shown to produce drag not associated with any useful purpose. The high wing loading used in these design studies will promote the use of heavier skin gages throughout the whole airplane than is now the practice. Some structural and perhaps manufacturing research is necessary to allow the employment of heavy gages without too much sacrifice in weight.

Propellers

It is well known that serious losses in propulsive efficiency occur when the helical tip speed of the propeller blades—the resultant of the forward and rotational speeds—approaches or exceeds the speed of sound. Obviously, when the airplane itself is traveling at a high percentage of the speed of sound, such losses are very difficult to avoid. In this study the authors wished to determine as definitely as possible just what efficiencies could be expected on the basis of available information.

The N.A.C.A. has tested[4] a three blade tractor propeller on a streamline liquid-cooled nacelle with a spinner at blade angles up to 60° at 75 percent of the radius (.75R). The results are shown on Fig. 2 in the form of a "design chart," consisting of curves of V/nD *vs.* speed-power coefficient C_S for different blade angles with propulsive efficiency contours cross plotted. Extrapolated values are indicated by dotted lines.

Fig. 3 shows Weick's[5] well-known family of curves for the tip speed correction factor, F_t, based on N.A.C.A tests. Weick obtained the effect of J (V/nD) by computing from the test data the effect of tip speed on the L/D of the propeller airfoils and then computing the efficiency at values of J beyond the range covered in the tests for those values of L/D. On that basis, assuming that the typical section is that at .75R, the value of F_t for a given tip speed would increase with J, up to a value somewhat above 2, and then decrease, slowly at first, but more rapidly as J becomes extremely large. In view of the uncertainties involved, it was considered reasonable to use a single curve, the one shown solid on Fig. 3, for values of $J \geqq 2$. For convenience, the tip speeds which give decreases in efficiency of .005, .01, .02, etc., based on an average un-

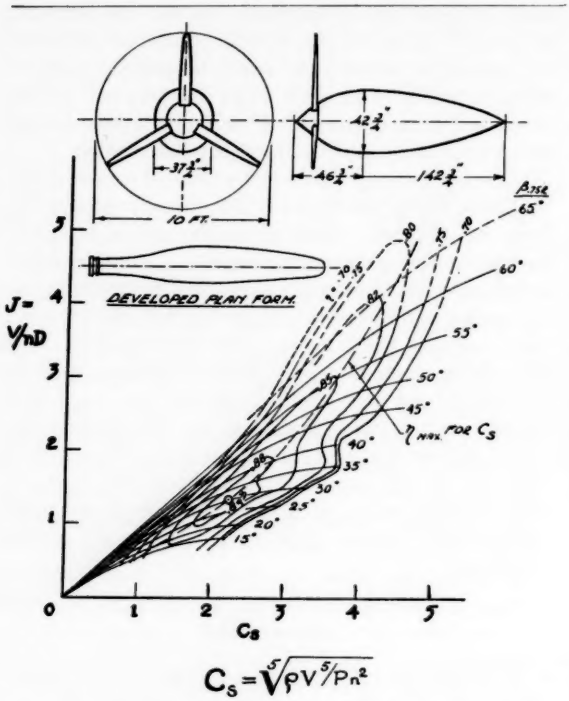

FIG. 2. Design chart, 3-blade Navy 5868–9 tractor propeller, liquid cooled nacelle with spinner.

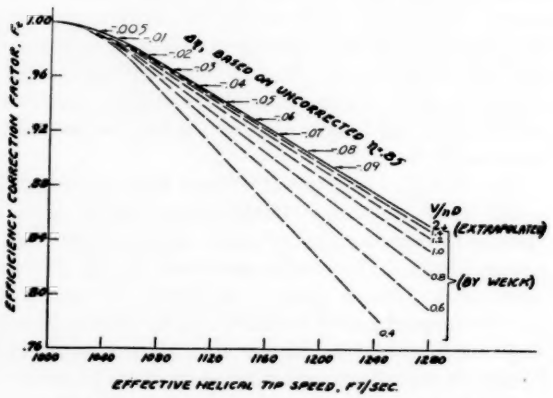

FIG. 3. Efficiency correction factor for tip speed.

corrected efficiency of .85, have been marked on the curve.

At altitude, the actual helical tip speed must be multiplied by f_c, the ratio of the speed of sound at sea level to the speed of sound at altitude (assuming standard air conditions), to obtain the equivalent helical tip speed. Hamilton Standard[6] has introduced corrections to tip speed for blade thickness (f_h) and for blade angle of attack (f_α). The necessity for the latter type of correction is confirmed by recent N.A.C.A. results.[7] In accordance with the system developed by Hamilton Standard, the abscissa of Weick's curves will be taken as the "effective tip speed."

$$\text{E.T.S.} = \frac{\pi N D f_c f_h f_\alpha}{60 \cos \phi_t} = \frac{88 \pi V f_c f_h f_\alpha}{60\ J \cos \phi_t} \qquad (1)$$

where ϕ_t is the angle of advance (the angle between the direction of motion of the blade element and the plane of rotation) at the propeller tip. Values of f_c and f_α are shown on Fig. 4.

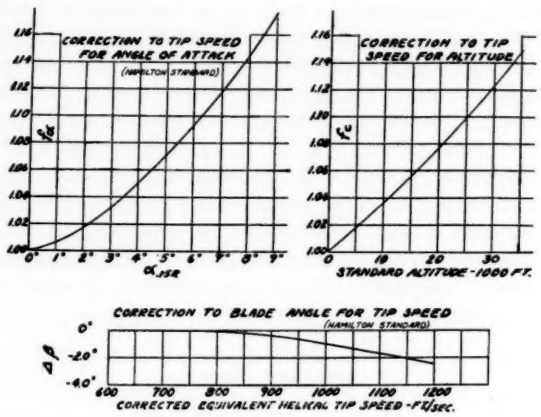
CORRECTION TO TIP SPEED FOR ANGLE OF ATTACK
(HAMILTON STANDARD)
CORRECTION TO TIP SPEED FOR ALTITUDE
STANDARD ALTITUDE - 1000 FT.
CORRECTION TO BLADE ANGLE FOR TIP SPEED
(HAMILTON STANDARD)
CORRECTED EQUIVALENT HELICAL TIP SPEED - FT/SEC.

FIG. 4. Tip speed correction factors.

The blades of the propeller tested by N.A.C.A. (Bureau of Aeronautics Design 5868–9) were rather thick, having a thickness to chord ratio at .75R of $h/b = .090$, which gives a tip speed correction[6] for thickness, $f_h = 1.033$. The values $h/b = .080$, $f_h = 1.01$ were considered to be more nearly normal, and were used for the purposes of this study.

When definite values of speed, altitude and blade thickness ratio are assumed, Eq. (1) becomes

$$\text{E.T.S.} = \frac{\text{Constant}}{J \cos \phi_t / f_\alpha} \qquad (2)$$

Curves of $J \cos \phi_t/f_\alpha$ *vs.* J for several values of $\alpha_{.75R}$, the angle of attack of the blade section at .75R, are shown on Fig. 5. It should be noted that when α is zero or negative, f_α is taken equal to 1.0, so that $J \cos \phi_t/f_\alpha$ becomes $J \cos \phi_t$.

At low tip speeds, $\alpha_{.75R} = \beta_{.75R} - \phi_{.75R}$ where $\beta_{.75R}$ is the blade angle at .75R. Since $\phi_{.75R}$ is a function of J, a definite angle of attack corresponds to every pair of values of J and $\beta_{.75R}$; that is, to every point on the design chart.

For effective tip speeds above 600 ft. per sec., Hamilton Standard has derived the blade angle correction, $\Delta\beta$, shown on Fig. 4. Then $\alpha_{.75R} = \beta_{.75R} + \Delta\beta - \phi_{.75R}$. Curves of $J \cos \phi_t/f_\alpha$ have been drawn on Fig. 5, for various blade angles and effective tip speeds.

A portion of the design chart, Fig. 2, was re-plotted to an enlarged scale on Fig. 6. A speed of 500 m.p.h. at 15,000 ft. was assumed. Then, from Eq. (1)

$$\text{E.T.S.} = 88\ \pi\ 500 \times 1.055 \times 1.01\ f_\alpha/60\ J \cos \phi_t$$

$$J \cos \phi_t/f_\alpha = 2456/\text{E.T.S.} \qquad (3)$$

Effective tip speeds giving propulsive efficiency reductions of .005, .01, .02, etc., were read from Fig. 3 and the corresponding values of $J \cos \phi_t/f_a$ were computed from Eq. (3). Values of J at various values of $\beta_{.75R}$ were then read from Fig. 5. When these J's were entered on the $\beta_{.75R}$ curves of Fig. 6, curves of constant $\Delta\eta$ could be drawn in. Finally, contours of constant corrected efficiency were plotted by subtracting the values of $\Delta\eta$ from the uncorrected efficiencies. The maximum corrected efficiency for 500 m.p.h. at 15,000 ft. was found to be .818.

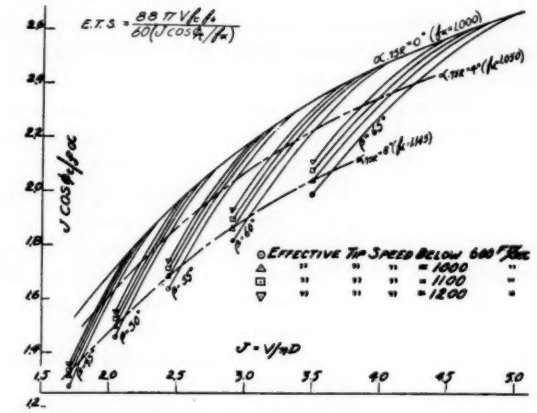

FIG. 5. Effective tip speed factor—J cos ϕ_t/f_a.

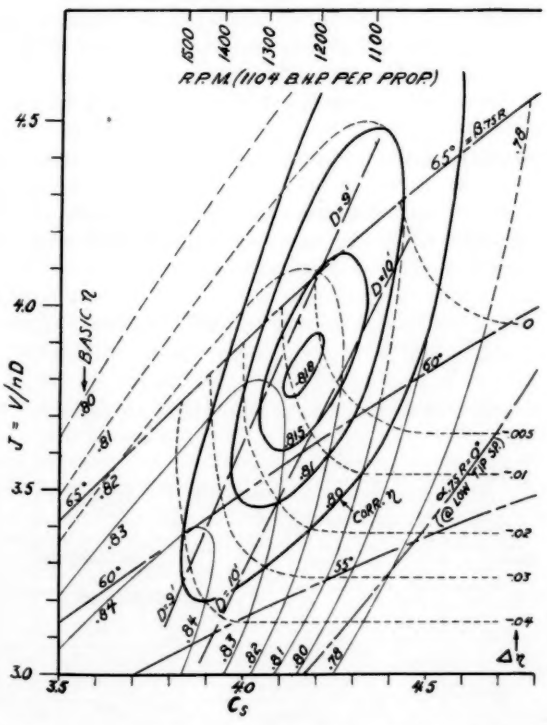

FIG. 6. Determination of corrected propulsive efficiency, 500 m.p.h. at 15,000 ft. (Also propeller diameter and r.p.m. for Design B.)

In the same manner, the highest corrected efficiencies for other speeds and altitudes were determined. Sample plots are shown on Fig. 7. It can be seen that as the speed and altitude are increased, the tip speed correction forces the optimum corrected efficiency point further toward the upper right hand corner of the design chart (to higher values of J and C_s) and further away from the point of maximum basic or uncorrected efficiency, which was .89 at $J = 1.45$, $C_s = 2.33$ (Fig. 2).

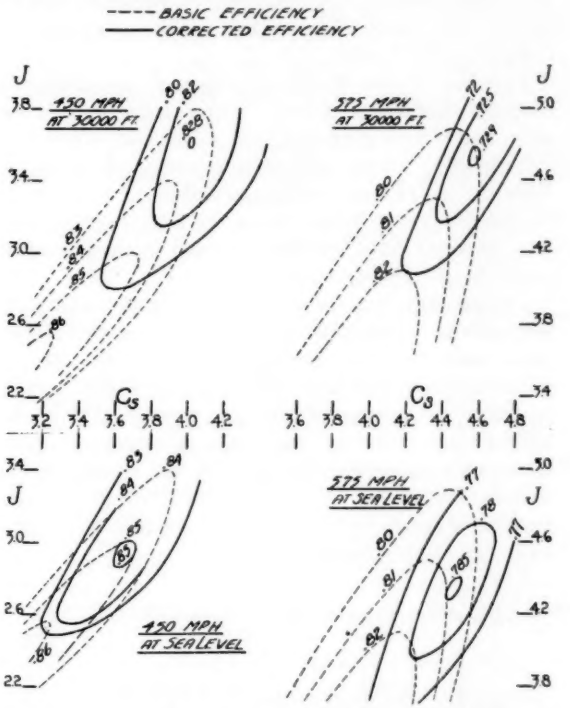

FIG. 7. Corrected propulsive efficiencies at several speeds and altitudes.

The optimum corrected efficiencies are plotted against speed for various altitudes on Fig. 8. These efficiencies are obtainable and are the highest which can possibly be obtained, on the assumption that: (1) The propeller and nacelle are geometrically similar to the setup tested by N.A.C.A. and sketched on Fig. 2 (with the exception that the blade thickness is assumed to be somewhat less than that of the propeller tested); (2) the method of correcting for tip speeds is valid; (3) Reynolds Number and compressibility effects on the propeller as a whole can be neglected provided the tip speed correction is applied.

Unquestionably, the matter of propeller corrections requires and deserves further systematic testing by the research establishments. The correction data used are thought to be the best available.

The effect of compressibility on the propeller, in addition to tip speed correction is probably a question of the critical compressibility speed of the blade shanks.

It is believed that this can be controlled by the proper use of streamline cuffs and spinners. Blades of plastic material could be constructed with good airfoil sections all the way in to the spinner, and may be essential at the highest speeds.

Higher efficiencies than the optimum shown might be attained by: (1) a propeller of lower solidity (narrower blades or two blades instead of three); (2) more efficient nacelle arrangement (smaller nacelle, pusher propeller); (3) means for increasing basic efficiency at large blade angles; (4) reduction of tip speed loss by special high speed blade airfoil sections delaying the compressibility burble.

Proposal (1) has the disadvantage of increasing the propeller diameter required. The possible gain is not very large, and probably not worth the difficulties introduced. In fact, airplane design limitations usually force the use of high solidity propellers on machines of the racing type. This reduces the obtainable propulsive efficiency, and has been avoided in these studies, partly by the use of twin propellers.

Pusher propellers, when employed with small well-streamlined nacelles, are reported to be more efficient than similar tractor arrangements.[8] On the designs presented here, pusher propellers are used with nacelles just large enough to fair into the spinners. It is estimated conservatively that this arrangement gives efficiencies one percent higher than the tractor nacelle installation of Fig. 2. Therefore in computing the maximum speeds of these designs, .01 has been added to the efficiencies shown on Fig. 8.

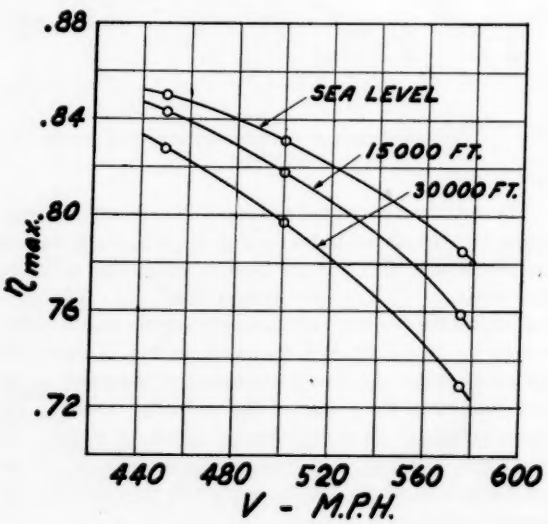

FIG. 8. Maximum propulsive efficiency corrected for tip speed, 3-blade tractor propeller, liquid-cooled nacelle with spinner.

Maximum efficiency *vs.* V/nD envelope curves from the N.A.C.A. test data[4] are shown on Fig. 9, for the liquid-cooled nacelle set-up of Fig. 2, both with and without a spinner. Theoretical curves have been added, computed on the basis that the efficiency of the propeller may be considered equal to that of the blade element at .75R, which is given by the simple blade element theory as[5]

$$\eta = \frac{\tan \phi_{.75R}}{\tan (\phi_{.75R} + \gamma)}$$

where $\gamma = \cot^{-1} (L/D)$ for the airfoil section at .75R. Curves were plotted for $\gamma = 3°$ and $\gamma = 4°$, corresponding to values of L/D of 19.1 and 14.3, respectively.

It will be seen that the actual efficiencies reach a peak at a much lower V/nD and decrease much more rapidly for V/nD greater than the optimum than the efficiencies shown by the theoretical curves. The decrease is more pronounced when the spinner is not used. This suggests that the cause may be, at least in part, the drag of the blade shanks, which is due almost entirely to the forward speed and consequently should have more effect as the ratio of forward to rotational speed increases. Cuffs should bring the actual efficiency curves nearer to the theoretical at high V/nD, but the authors do not feel that information obtained to date justifies any definite assumption in this regard.

Probably the most promising method for increasing basic efficiency at high blade angles is by the use of opposite-rotation propellers, which eliminate the loss due to twist in the slipstream. Because adequate published data on this at sufficiently high blade angles and values of V/nD were not available, no attempt was made to evaluate it in this paper. However, it is unquestionably a very important consideration.

The propeller diameter and r.p.m. needed for optimum efficiency for Design B will be determined. The maximum speed is approximately 500 m.p.h. at 15,000 ft, so Fig. 6 will be used. The engine horsepower is 2300 and the transmission is estimated to be 96 percent efficient, so that the b.hp. delivered to each propeller is 2300 × .96/2 = 1104. Then,

$$C_s = \frac{.638\ \sigma^{1/5} V}{\text{hp.}^{1/5} N^{2/5}} = \frac{.638 \times .629^{1/5} \times 500}{1104^{1/5}\ N^{2/5}} = \frac{71.5}{N^{2/5}}$$

$$J = 88\ V/ND = 88 \times 500/ND = 44{,}000/ND$$

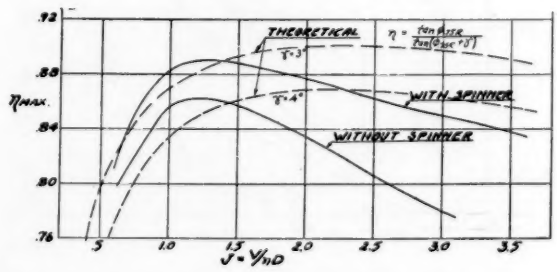

FIG. 9. Efficiency envelopes, 3-blade Navy 5868-9 tractor propeller, liquid-cooled nacelle.

Assumed N, r.p.m.	1100	1200	1300	1400	1500
$N^{3/4}$	16.47	17.05	17.60	18.13	18.63
C_s	4.35	4.20	4.06	3.94	3.84
J (D = 9 ft.)	4.44	4.07	3.76	3.49	3.26
J (D = 10 ft.)	4.00	3.67	3.38	3.14	2.93

The values of J for propellers 9 feet and 10 feet in diameter have been plotted against C_s on Fig. 6 and a scale of abscissa in r.p.m. has been added. It will be seen that a diameter of approximately 9 ft. 4 in. gives optimum efficiency and that the r.p.m. required is about 1230. The variable speed transmission would be utilized to obtain a considerably higher r.p.m. for take-off.

Optimum Altitude

Heinkel has shown[3] that the optimum critical altitude above 450 m.p.h. decreases with increasing speed due to compressibility. Fig. 10 shows Heinkel's calculation of the variation of optimum altitude with speed. The curves of Fig. 8 also show a loss in propulsive efficiency with increasing altitude. For the very fast airplane these factors dictate flight altitudes below those which are attainable by supercharging through the use of an exhaust driven turbo or an equivalent device. The optimum critical altitude for airplanes traveling up to 550 m.p.h. therefore appears to be the highest altitude that can be obtained by the use of an engine equipped with a direct-driven compressor. In practical application, this altitude, with ram, may be taken at 15,000 feet. Extra supercharging is required to go much higher. The complication of devices to supply this additional supercharging are not justified until an altitude of about 25,000 or 30,000 feet is reached, because the performance of the airplane would not be improved to any substantial degree between 15,000 feet and 25,000 feet by the addition of the supercharging apparatus, due to the additional weight and drag of the supercharger and its accessories. At 25,000 feet or above, the very fast plane is above the optimum altitude; at least considering the efficient use of power. From these considerations a critical altitude of 15,000 feet was selected for these investigations.

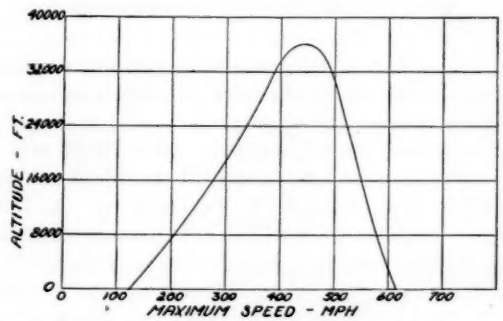

Fig. 10. Optimum flight altitude (by Heinkel[3]).

Drag

In Table 3 are presented some values of equivalent parasite area which represent possible attainments within two years. These are compared with values existing in airplanes now in use, the basic designs of which are from two to four years old. The equivalent parasite area, f, which is equal to the drag coefficient times the wing area, is used as the most convenient figure for tabulation. The possible values are based on Design A with 1150 hp. and 110 sq. ft. of wing area. The others are based on airplanes of about the same power, but with considerably lower wing loadings according to present-day practices.

Table 3

Values of Equivalent Parasite Area f for Design "A" and Similar Airplanes

	Possible Within Two Years	Best Current Practice
Wings	.77	1.50 to 2.00
Tail Surfaces	.234	.35 to .400
Fuselages	.62	1.20 to 2.50
Cockpit Enclosures	0	.045 to .125
Engine Cooling		
Prestone Cooling (Heat Dissipation)	.058	.130 to .200
Prestone Radiator Ducts (External + Internal)	.039	.300 to .750
Oil Cooling (Heat Dissipation)	.015	.033 to .041
Oil Cooling (External + Internal)	.010	.038 to .500
Landing Gear	0	.05 to .52
Carburetor Air Intake	.070	.07 to .50
Exhaust Stacks	0	.07 to .20
Cooling Louvers and Leakage	0	.00 to .36
Total	1.816	

Fig. 11 is a graphical representation of the calculated drag values for all the designs, not including induced drag. The principal point disclosed by this chart is the nearly linear increase in wing and tail drag with increase in power and gross weight. However, these drags do not increase directly as the power, but at a lesser rate. Fuselage drag increases non-linearly and at a declining rate. Other drag is approximately in proportion to power.

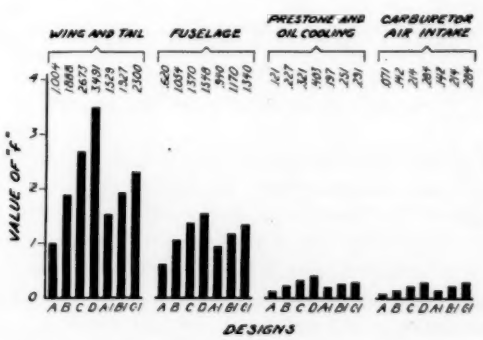

Fig. 11. Equivalent parasite area breakdown.

Fig. 12 shows the drag values expressed as percentages of the total airplane drag. It may be of some interest to note that in the series A, B, C, D in which the wing loading is constant, the percent wing and tail drag increases with increase in size, whereas the percent fuselage drag decreases. In Designs A, A-1, B-1, and

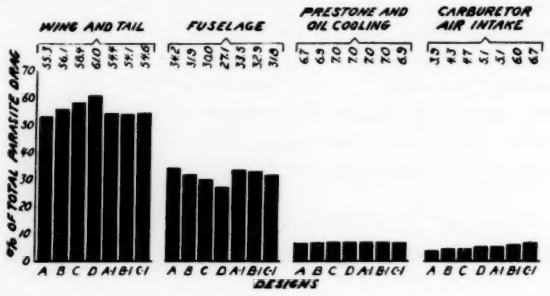

FIG. 12. Drag breakdown in percent of total.

C-1, where the loading increases with size, the wing and tail drag is nearly a constant percentage of the total, and the fuselage drag is more nearly so than in the first series.

SPEED

The results of the speed determination are plotted in Fig. 13. The studies which were made for the pur-

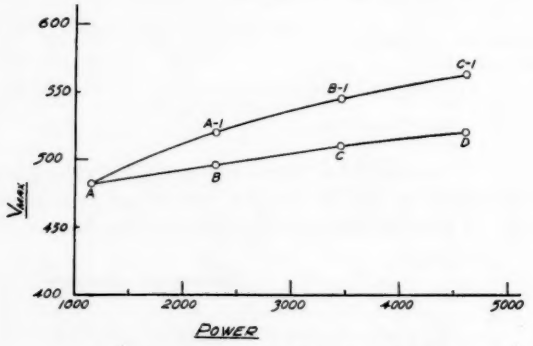

FIG. 13. Variation of speed with power.

pose of surveying the possibilities of increases in power and in wing loading clearly show that not much is to be gained by increase in power alone. In the first series, shown by the lower curve, a 300 percent increase in power results in only 7.9 percent increase in speed. The upper curve with the same increase in power shows a 16.8 percent increase in speed.

The increase in weight and dimensions which accompany an increase in power demonstrate the inefficiency of obtaining increase in speed by using larger engines. Research directed toward lowering the weight of engines per unit output, improvement in aerofoils and other bodies for speeds approaching the speed of sound, the development of materials of superior strength weight ratios, and improvement in structural design efficiency, are fields in which more remunerative results may be obtained.

THE FASTEST AIRPLANE

Fig. 14 is the familiar graph showing the advances in speed with the passing of years. On the right hand

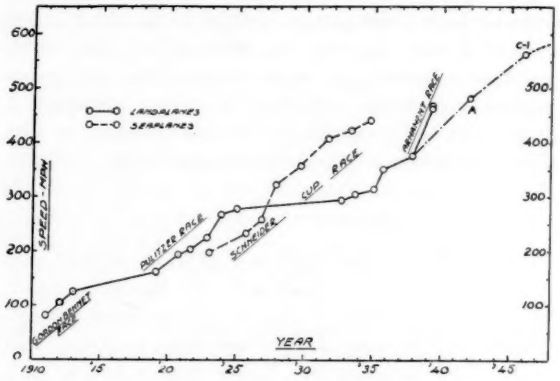

FIG. 14. World record for maximum speeds.

end of this plot is an extrapolation, based on these studies, to show the speeds which the authors believe are possible within two to six years.

The highest speed already achieved is 469.22 m.p.h., the world's record performance of the Messerschmitt Me.109R airplane made in Germany on April 26, 1939. The present record holder is basically an Army Pursuit plane, and hence may be said to be the product of a different sort of "race," the current one in armament. It is probably not the last mark which will be established by a machine of that category. It is certainly fair to state, however, that the speed record was not set by a purely service airplane, but by a cleaned-up cut-down version, with military equipment omitted and with the engine arranged to give a "flash" power far above its normal rating.

It is interesting to compute the horsepower necessary to make 469 m.p.h. Favorable assumptions are made that the airplane was light, the wings were clipped, the aerodynamic design was as good as the best drag values herein presented for "best current practice." All drag for prestone and oil cooling was deducted, on the assumption that the air intakes were cowled over and that a self-contained evaporation system was used which was sufficient for the few minutes of flight required, and allowance was made for a gain in speed due to the dive permitted by the rules. The record was made over a 3 kilometer course. The test was run under the F.A.I. rules, which require that the airplane fly practically level at a height of not more than 75 meters while over the course and for an approach distance of 500 meters. However, a maximum height of not more than 400 meters can be obtained during the flight. If the course is flown at a height of 50 meters,

it is possible to dive 350 meters, or 1150 feet, before leveling out at the start of the 500 meter approach. Garner and Cushing[9] have calculated the speed which can be gained by such a dive, and have shown that their calculations were checked very closely in flight. An upper limit is furnished by the fact that the increase in kinetic energy cannot exceed the loss in potential energy. Actually, the speed which can be gained is related in a rather complicated manner to the maximum negative and positive acceleration permissible in entering and pulling out of the dive. In the case of the Supermarine S6B, the loss in potential energy would have produced a speed increase of 61 ft. per sec. if it could have been completely converted into kinetic energy. The pilot actually gained 25.5 ft. per sec. in average speed over the course. (Calculations assuming $^1/_2\ g$ acceleration in entering the dive and 3g in pulling out gave 24.5 ft. per sec.) However, it is indicated that the machine was allowed to lose 50 m. altitude while traversing the three-kilometer course. This would not be allowed under the present rules, and Fig. 6 of Garner and Cushing's paper shows that horizontal flight over the course would have reduced the gain from 25.5 to 22 ft. per sec. This is 36 percent of the gain from the available potential energy.

The potential energy available in the case of the special Messerschmidt is about $5000 \times 1150 = 5{,}750{,}000$ ft. lb. If the level speed is taken as 456 m.p.h. = 669 ft. per sec.,

$$5{,}750{,}000 = (5000/2g)\ (V^2 - 669^2)$$

$V = 723$ ft. per sec. = Average speed over course using all the potential energy.

The actual increase in average speed over the course will therefore be $.36\ (723 - 669) = 19.5$ ft. per sec., or 13 m.p.h. A level speed of 456 m.p.h. should therefore suffice to equal the Messerschmidt record of 469 m.p.h.

The computation of horsepower required to make 456 m.p.h. at sea level under the above assumptions indicates that the Daimler Benz motor rated at 1175 hp. was producing about 2150 hp. during the few minutes required to fly the speed course.

It will be noted that the present speed record is above the trend predicted by the authors. Substantiation for the belief that the present record probably does not indicate the direction of the trend line lies partially in the conclusions drawn from these design studies, and partially from the assumed advantage which the record holder had as a result of an unorthodox method of cooling. The world record speeds plotted on Fig. 14 were all made near sea level, and presumably with flash engine ratings and the amount of diving permitted by the rules. It is realized that the speeds estimated for the designs studied in this paper are in a slightly different category, since they are obtained at altitude, with no increase above rated power, and without a diving start. Nevertheless it was thought to be of interest to plot these predictions with the speeds of the past and present record holders.

Design A represents what is believed to be possible of accomplishment within two years. Design C-1, a super-powered airplane should raise the speed to approximately 560 m.p.h. in six years. Beyond this, any predictions are difficult and are made with considerable risk. However, the authors are lured to enter their guess with others who have ventured to predict the maximum speed of the fastest airplane. This is done with the reservation that the prediction applies only to aircraft using conventional principles of sustention and propulsion. Allowance is made for further reduction in wing area possibly with assisted take-off, for refinement in airfoils, a gain at very high speeds through the use of oppositely rotating propellers, and some recovery of wasted energy from the exhaust and the radiator heat by obtaining supplementary thrust on the jet-propulsion principle. The limitations due to compressibility are also taken into account.

This speed of the fastest airplane is set at 650 m.p.h.

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The Effect of a Variable Gear Reduction on Propeller Performance in Modern Airplanes

FRANK W. CALDWELL

Hamilton Standard Propellers, United Aircraft Corporation

THE question of application of a two-speed reduction gear has been under consideration for some time,[1,2] and experiments along this line were carried out before the universal introduction of the controllable pitch propeller. The original conception of the utility of this device was the control of engine r.p.m. with supercharging to maintain a uniform power output at various altitudes. If such effects as compressibility at high tip speeds of the propeller and variation in attitude of the airplane are neglected, the change of gear ratio can be visualized as a better method of controlling the engine r.p.m. than the procedure of changing propeller pitch because the propeller driven by the variable reduction gear would operate near the V/nD of best efficiency at all altitudes, whereas the controllable pitch propeller would depart rather widely from its best V/nD. Actually, however, the case for the controllable pitch propeller is not bad even for these conditions, because the efficiency changes very slowly over a considerable range of V/nD at any one pitch setting, whereas the power absorbed varies quite rapidly.

When airplanes with moderately high speed, around 200 m.p.h., came into use the situation with respect to the change gear was radically changed. For these airplanes the pitch angles of the propeller blades are necessarily moderately high, say, in the neighborhood of 30° at the three-quarter radius point, so that the propellor airfoils without pitch change are completely stalled at take-off. Under these conditions the change gear would permit an increase in engine r.p.m. but the propeller efficiency with fixed pitch propellers is so low that the corresponding increase in engine power contributes very little to the thrust.

This particular condition can be improved only by the controllable pitch propeller which permits the use of low pitch angles for take-off. Fortunately, the low pitch angles in this range of performance also lead to about the proper increase in engine r.p.m. so that both the improved propeller efficiency and the maximum horsepower of the engine can be made available to help the take-off. The principal part of this gain can be realized by the use of the two-position propeller in which a low pitch setting is used for take-off and climb, and a high pitch setting for level flight.

The two-position propeller, however, does not meet the requirements for high altitude supercharging very well, since a high pitch suitable for level flight at high altitude leads to material loss in engine power due to reduction in revolutions in level flight near the ground; while the low pitch setting necessary for take-off would lead to excessive revolutions and loss of propeller efficiency if used in level flight, even near the ground.

Obviously, this situation can be very much improved by a continuous series of pitch settings, so that the proper setting for each condition of flight can be chosen at will by the pilot. This type of operation, however, would call for continuous adjustment of pitch on the part of the pilot in order to obtain the best results and would be excessively burdensome during variations in the conditions of flight, such as take-off, climbing, maneuvering, and flying at various altitudes. In order to meet this requirement the constant speed type of propeller was developed, in which the revolutions of the engine are maintained constant by variations in the pitch of the propeller, this variation being brought about by the use of some type of engine-driven speed governor. In order to give the pilot the choice of the regimes of take-off revolutions, full-power revolutions and cruising revolutions, the governors are provided with an adjustment which permits the pilot to set the governor for any desired r.p.m.

This procedure meets the airplane-engine-propeller performance requirements in a fairly satisfactory manner by the use of a comparatively simple mechanism.

However, the procedure has certain limitations from the standpoint of the engine as well as that of the propeller, and these limitations are beginning to become important both in the case of airplanes of extremely high speed and in the case of airplanes of extremely long range.

The situation for the airplane with very long range is not extremely acute at the present time, although it appears likely that it may become so if the ultimate in long-range performance is desired.

The mechanical and thermal efficiencies of most aircraft engines are maintained at their best values by operating the engine at a fairly high mean effective pressure. For very long-range operations, however, it is often desirable to operate the engines at about 35 percent of the maximum power rating. Considerations of good engine efficiency would lead to the use of a b.m.e.p. of around 70 percent of the maximum normal value, so that only about 50 percent of the

Presented at the Power Plants Session, Eighth Annual Meeting, I.Ae.S., New York, January 24, 1940.

maximum normal revolutions could be used if full advantage of the possibility of low fuel consumption is to be taken.

Fortunately, the propeller is capable of operating over a fairly wide range of power near the conditions of V/nD for best efficiency without serious loss in efficiency. However, when the value of V/nD departs from the best value by about +10 percent or −5 percent, the efficiency begins to drop off rapidly.

The result of this characteristic of the propeller is that a wide departure from the design pitch ratio, which would be necessary to absorb 35 percent of the normal power at 50 percent of the normal revolutions, may lead to a loss of propeller efficiency of the order of 10 percent. This loss of propeller efficiency is of serious importance in connection with airplanes of very long range. For instance, if an airplane with a range of 5000 miles, employing four engines with a normal rating of 2000 hp. each, were used at 35 percent power, the fuel consumption at 0.4 lb. per hp. per hour would be 1120 lb. per hour. If the airplane were assumed to have a cruising speed of 200 m.p.h., the resulting 25-hour flight would require the consumption of 28,000 lb. of fuel. Consequently, each one percent of fuel saved would lead to a credit of 280 lb. to be applied to payload.

If the change gear were applied to this type of airplane, the propeller could be operated at its V/nD of maximum efficiency, and the engine speed could be chosen independently to give the best fuel consumption. The present practice in a case of this kind is to select a compromise engine speed to give an optimum value of the quotient of propeller efficiency divided by fuel consumption of the engine. This procedure may lead to a propeller efficiency perhaps 7 percent less than the best obtainable. The compromise leads to an engine efficiency of 4 percent worse than the best possible figure. The application of the change gear under best possible propeller operating conditions and best engine operating conditions might lead to an overall improvement of 10 percent in net fuel consumption. This figure is of course variable from case to case, depending partly on the character of propeller installation allowed by the propeller-clearance limitation of the airplane.

Propellers for High-Speed Airplanes

The development of very high-speed airplanes in the 500-mile-per-hour class is introducing a number of new propeller problems calling for a radical revision of past design practices and leading to a new set of compromises in the selection of the propeller sizes.

Aircraft of this type will probably be confined for some time to the field of military fighters and pursuit planes in which maximum performance is given the highest rating and range is of somewhat secondary importance. It is true that the change gear can be used with such airplanes to improve the range in much the same way as with the long-range types but the fuel saving would not be sufficient to warrant the weight and complication of the gear. The primary justification for the gear will have to rest on other phases of performance.

One of the most obvious problems is the take-off performance which must be fairly good if these airplanes are to be usable in a practical way. There are a number of new factors entering into the problem of propeller design for this type of airplane and several of these factors tend to make the take-off regime particularly difficult to deal with.

In the past, take-off considerations have been given primary consideration in the selection of propeller sizes and it has been possible to select reduction gear ratios and propeller diameters in such a manner as to give an oversize propeller for maximum speed of the airplane. This oversize propeller permitted the use of a relatively low blade angle setting for take-off with consequent improvement in propeller efficiency. In many cases a propeller diameter about 10 percent above the ideal value for maximum airplane speed with an efficiency loss of about one percent has been utilized. This oversize propeller, however, often led to an improvement of take-off thrust of 10 to 15 percent.

A further improvement in take-off conditions has been obtained in many cases by the expedient of using a slightly higher r.p.m. rating for the engine on take-off than that used in level flight, so that a still lower pitch angle could be used for take-off. This procedure is necessarily limited, first, by the mechanical design of the engine, which permits a rather limited degree of overspeeding; and, second, by the propeller tip speed which cannot reach excessive values without serious loss in efficiency.

In evaluating the effect of overspeeding the propeller at take-off, two opposing tendencies have to be taken into account. Increase in propeller speed permits a reduction in blade angle, and this reduction gives an improvement in propeller efficiency down to a blade angle of about 12° at the three-quarter radius. In practice, increase in tip speed nearly always leads to a loss in efficiency and, under take-off conditions, the loss begins at a tip speed of 600 to 800 feet per second, and the rate of loss becomes very high at a speed of 1000 feet per second.

The selection of the best take-off r.p.m. thus becomes a matter of compromise between these opposing tendencies. If the blade angles are lower than 20° it is rarely advantageous to increase the tip speed beyond 1000 ft. per sec. If the blade angle is higher than 30° it is sometimes advantageous to maintain the r.p.m. but to reduce the engine power, since the lower power permits a reduction in angle and the corresponding gain in propeller efficiency may be at a greater rate than the loss in engine power.

With airplanes of extremely high speed it is no longer

possible to follow the expedient of using oversize propellers. With these airplanes the forward speed of the plane becomes a serious factor in its effect upon the tip speed of the propeller. In order to hold the tip speed below the compressibility point, it is necessary to use a low speed of revolution, resulting in a large propeller diameter, and the situation is further aggravated by the fact that these airplanes are usually rated at a fairly high altitude so that the permissible tip speed is materially lowered, due to the temperature correction. At the same time, the airplane has to be a small, compact structure in order to make the high speed possible, so that large propeller diameters cannot be tolerated without excessive penalties to the airplane design. For this reason it is usually necessary to select a propeller diameter as small as possible without serious loss in efficiency, so that the propellers for this type of airplane have, in general, a diameter somewhat less than that corresponding to the V/nD for best efficiency.

The net result is that the pitch angle may reach a value of 60° or more at the three-quarter point, so that the pitch angles at take-off are still excessively high when adjusted to maintain maximum permissible revolutions for the engine. In a typical case, where the pitch angles at maximum speed at altitude are around 60°, the corresponding take-off angle at maximum engine revolutions may be about 25°.

The propeller efficiency is naturally very low at such a high blade angle so that there is a possibility for very great improvement by the use of the change gear which would permit a substantial increase in propeller r.p.m. and corresponding decrease of blade angle without excessive overspeeding of the engine. As will appear below, the propeller requirement will call for an overspeed of about 50 percent at take-off. If the engine were mechanically and thermally capable of such an overspeed rating the military requirement would probably call for a similar overspeeding for short intervals in flight, so that assignment of such a large overspeed rating of the engine for take-off does not appear to be a happy solution.

Fortunately, a considerable amount of overspeeding is possible for the propeller in this case without excessive tip speeds because the influence of the forward component and the altitude correction at top speed leads to a very low rotational tip speed, which will be of the order of 700 ft. per sec. for the typical 500 m.p.h. airplane. Since the effect of the forward component is not present at take-off, it is possible to increase the propeller revolutions by about 50 percent above the r.p.m. at maximum airplane speed without going substantially beyond a tip speed limit of 1000 ft. per sec.

In several typical cases which have been studied, the use of the change gear and corresponding overspeeding of the propeller will lead to an improvement in take-off thrust of about 20 percent, as compared to the present practice where a single gear ratio is used. This need for the two-speed gear will be present whether a single propeller is used or whether two propellers rotating oppositely on the same shaft are used.

For the very high-speed airplane, the use of a two-speed reduction gear has a great advantage and the improvement in performance in this case is so important that it appears that a variable reduction gear will be indispensable for this type of airplane. Of course, a two-speed gear would be adequate for the solution of this particular problem. However, it is of interest to consider what advantages and refinements in performance could be obtained by the use of a continuously variable gear ratio.

In looking over the cases which have been considered, it may appear paradoxical to the engine designer that the original conception of the two-speed gear called for the use of low propeller speed at take-off and low altitude, with high propeller speed at high altitude; whereas the present requirement of the high-speed airplane calls for high propeller speed at take-off and low propeller speed in level flight at high altitude. Again, the requirement for the best possible cruising range calls for the use of moderately low propeller speed at take-off with relatively high propeller speed for cruising.

There appears to be no obstacle to the design of a two-speed gear beyond the usual problems of obtaining the lightest possible gear consistent with good performance.

The principal new problem is one of synchronizing the two shafts at the time of changing gears so as to avoid excessive shock in the mechanism. Fortunately, aeronautical equipment already developed for automatic synchronizing can be made use of for this purpose.

In the type of synchronizer developed by Hamilton Standard, a master alternator would be provided to be driven by the engine shaft and a second alternator would be driven through suitable gearing by the propeller shaft. Where engine and propeller are disconnected, the propeller governor r.p.m. would be brought into correct synchronization with the engine shaft by means of a synchro-head actuated by the slip frequency of the two alternators. For the two-speed gear it would be necessary to provide two alternators, one for each gear ratio on either the engine shaft or propeller shaft. This equipment has already been developed to a practical point and the precision of synchronization is ample for the purpose of gear shifting.

Considering the case of the two-speed gear, it will be necessary to study the propeller characteristics in detail for each particular airplane application and select two gear ratios representing the best compromise for the particular airplane. This procedure will lead to a demand for a large number of gear ratios which, of course, will make a very difficult manufacturing problem for the engine makers.

The weight added by the two-speed gear would run about 0.06 lb. per hr. The synchronizing equipment would probably add about 25 lb. to the normal governor weight. These weight figures will have to be evaluated for specific cases in determining whether the gear is worthwhile.

The question has been raised as to whether a continuously variable reduction gear would permit improving the propeller efficiency at various altitudes. The propeller for the 500 m.p.h. airplane is necessarily operating at a V/nD far beyond that at which best efficiency can be obtained. The rotational speed of the propeller is limited at high altitude by temperature conditions and by the effect of the forward component of airplane velocity on the resultant tip speed. Both the temperature and forward component of resultant tip speed lead to a possibility of increased speed of rotation at lower altitudes. Such an increase would lower the V/nD of the propeller resulting in an improvement of propeller efficiency. This procedure would be favored by the selection of undersized propellers for the condition of maximum speed at altitude.

In the actual cases studied, however, it has been found that the effect of density tends to make the high-altitude propeller oversized for the low-altitude condition, so that overspeeding leads to a loss due to too low an angle of incidence. Best propeller conditions are obtained by keeping level flight r.p.m. constant at all altitudes.

A slight gain in propeller efficiency in climb could be had by variations in propeller speed. This gain which might amount to 2 or 3 percent could not have a very serious bearing on the selection of the continuously variable gear *vs.* the two-speed gear.

If the continuously variable gear is to be justified from the performance standpoint, its value would have to depend mainly on engine design considerations. With a two-speed gear blower drive, there might be some advantages in compromising engine speed to minimize blower losses. However, this job could undoubtedly be done much more efficiently and perhaps more easily by the development of a continuously variable blower gear drive.

In the case of the turbo surpercharger there might be some advantages in increasing crank r.p.m. at maximum altitude to obtain power output with less boost from the turbo. These possible advantages appear minor, however, and it seems difficult to find sufficient performance advantage to warrant the continuously variable gear. If a continuously variable gear ratio of satisfactory design could be developed, however, it might prove much more economical for the engine manufacturer to go directly to this procedure in spite of the increased complication and inherently greater cost, since it would presumably be possible to build a single design for the various airplane applications. The requirements of any one airplane-propeller combination might be met fairly satisfactorily with the two-speed gear provided a sufficient choice of gear ratios were available, but the engine manufacturer will have a powerful incentive to develop the continuously variable gear in order to obtain some degree of continuity of production.

As the continuously variable reduction gear would permit complete freedom in the independent selection of engine speed and propeller speed, it is of interest to consider in what manner the speed of the two elements could be regulated.

It appears that it would be desirable to control propeller speed by means of a propeller shaft-driven governor which would maintain propeller r.p.m. by changes in blade angle. This governor would be provided with a maximum speed limit stop. The engine speed could be regulated by an engine-driven governor which would control engine speed by adjustment of the gear ratio. This governor could be provided with a manometrically actuated high-speed limit stop which would permit the most favorable maximum engine revolutions at each altitude. For maximum performance at any altitude, both propeller and engine governors would be set against the high speed stop.

The design of the continuously variable gear reduction may not prove feasible within the weight and efficiency limits permissible for aircraft use. The hydraulic transmission of the fluid coupling type appears attractive, inasmuch as this device has very desirable vibration insulating characteristics. Perhaps the weight might be brought down to permissible limits by the exercise of sufficient ingenuity in design. It does not appear possible, however, to reach a satisfactory level of efficiency over a wide range of speed ratios, with the hydraulic drive. In any event, the problem of the continuously variable gear ratio offers a fruitful field for inventive genius.

In conclusion, it may be said that the two-speed gear appears to have a useful application in improving the take-off of extremely high-speed airplanes and in improving the fuel requirements of airplanes of extremely long range. The continuously variable gear does not appear to be justified if one considers only the performance, but might be of practical advantage from the manufacturing standpoint if a satisfactory design could be developed.

References

[1] Watts, H. C., *Airscrew Development*, Journal of the Royal Aeronautical Society, Vol. 40, page 483, July, 1936.

[2] Jennings, W. G., *Variable Pitch Airscrews and Variable Gears*, Journal of the Royal Aeronautical Society, Vol. 38, page 2, January, 1934.

Problems in Weather Map Analysis and Forecasting in Connection with Transatlantic Flying

H. C. WILLETT
Massachusetts Institute of Technology

THE following remarks are based in part on the author's experience of the past summer in forecasting for the transatlantic survey flights of the American Export Airlines, and in part on experience gained during the past three years in the analysis of Northern Hemisphere weather maps, together with the analysis of North American aerological data.

Any discussion of transatlantic flight forecasting must be prefaced by a few general remarks on the basic requirements of such a service. It must be borne in mind that efficient transatlantic flight operations, especially in winter, will require dependable weather forecasts over a stretch of some 3000 miles of open ocean, extending from 48 to 72 hours ahead. This presupposes quite a different type of forecasting than, for instance, that required by domestic airlines, where usually an accurate 12-hour forecast, or at most one for 24 hours, is sufficient to meet individual flight needs. Furthermore, all the local topographical features of the flight region which are so important to much of the domestic airlines forecasting largely disappear in transoceanic forecasting. In other words, the transoceanic service calls for more emphasis on the basic long-range general type of forecast, with particular emphasis on winds aloft, rather than the typical short range specialized aviation forecast. The greater the time and space range of a forecast, the more important becomes the general basic forecast, and the less important the localized special details which are emphasized in the aviation type of forecast. Apart from the winds aloft, the occurrence of zones of heavy icing is the only characteristically aviation forecast item which needs to be stressed in the transatlantic flight forecasts.

Not only in comparison with domestic aviation forecasting, but also in comparison with flight forecasting for the present transpacific routes and the routes to Central and South America, the Atlantic forecast service offers peculiar difficulties. The Atlantic flight routes lie far enough north so that they come within the zone of strong cyclonic activity in winter, with its rapidly changing conditions and frequent strong winds over large areas. The Pacific and South American routes occasionally are affected by strong extra-tropical cyclonic activity, and occasionally by tropical disturbances, but by and large, conditions on those routes are comparatively steady and winds moderate. The danger of heavy icing which constitutes a real threat even at low altitudes over the western north Atlantic during the late winter will be encountered only at great heights on the Pacific and South American routes.

From the above remarks it will be seen that the basic requirement of a transatlantic flight forecast service is the preparation of a reliable general forecast across the Atlantic, extending at least 48 hours into the future, in which the following elements are given special attention: (1) the winds to be expected along the entire route from the ground preferably up to at least 10,000 feet; (2) during the coldest third of the year, the possibility of the occurrence of heavy icing at low levels; (3) the conditions to be expected at times of arrival and take-off at final and intermediate terminal points. In view of the difficulties which inevitably will be encountered during much of the year in transatlantic flight operations involving intermediate stops, the tendency will doubtless be toward non-stop operations between terminal points in the United States on one side and Great Britain or continental Europe on the other. Thus the forecast problem for the great part of the Atlantic ocean area will resolve itself into the forecasting of winds and of exceptional icing conditions.

On the basis of last summer's transatlantic forecast experiences, certain remarks on the adequacy of available data are in order. The following remarks apply to the conditions prevailing before the outbreak of war, which, of course, has led to a much less favorable state of affairs. With respect to surface observations, both from land stations and from ships at sea, the number and content of such reports meet reasonably satisfactorily the requirements of transatlantic aviation. This implies, to the author's way of thinking, the preparation of four surface maps per day extending from the west coast of North America eastward across the Atlantic to central Europe, with sufficient data to insure a reasonably complete and accurate analysis of this entire area north of latitude 30°N. This requirement has been reasonably well met only since the American ships during the current year have begun reporting four times daily instead of twice, and in complete international code for weather reports from ships at sea instead of the incomplete code previously used by American and British ships.

However, in spite of the sufficiency of land and ship weather observations, it should be stressed that by no means all of such observations are available for the

Presented at the Meteorology Session, Eighth Annual Meeting, I.Ae.S., New York, January 24, 1940.

use of the meteorologist on this side of the Atlantic. There is urgently needed one centralized agency to collect and transmit such reports to this side of the Atlantic, so that they can be made immediately available to all interested users. To a very limited extent this sort of service was performed during the early part of last summer by the French meteorological ship *Carimare*. However, during most of the period of the American Export Airlines survey flights the *Carimare* was off duty. In general it can be said of the situation last summer that any organization requiring meteorological data from the eastern Atlantic had to go to considerable effort and expense to acquire it, and even then by no means all of the observations from the east side of the Atlantic could be obtained. The Weather Bureau is at present taking steps to at least partially eliminate this difficulty. Of course, just at present the war eliminates both land and ship reports from the belligerent nations, not to mention many ship reports from non-belligerents.

With respect to aerological data from the middle Atlantic, both pilot balloon observations of winds aloft and temperature-humidity soundings, the situation is very different. Such observations are almost nonexistent, and the lack of such data is very serious in its effects on transatlantic aviation. Last summer the only pilot balloon reports available from the middle Atlantic were rather irregular observations from Bermuda and Horta, observations from the French ship *Carimare* when she was on station, and an occasional observation from one of the American Export steamships. Sometimes at the time of take-off of one of the survey flights there was not a single upper wind observation for the entire mid-Atlantic.

The situation was no better with respect to temperature-humidity soundings. The only observations of this type from the middle Atlantic were received occasionally from the *Carimare*. During the late spring and the month of June a temporary cooperative program of radio-sounding observations was initiated by a number of American agencies (the U. S. Weather Bureau, the U. S. Coast Guard, the Massachusetts Institute of Technology, and the Blue Hill Observatory of Harvard University) together with the French Meteorological Service. As a result of this program there were obtainable regular daily observations from St. Pierre, Newfoundland, from two Coast Guard Ice Patrol cutters, from Bermuda, from the *Carimare*, and from San Juan, which made it possible to extend the North American upper air charts far out over the western Atlantic. This was of great practical forecast value for this region, as is explained below, but unfortunately this cooperative effort terminated at the end of June, which was just the time the American Export Airlines survey flights commenced. Even the *Carimare* left her station and returned to France at this time, which left all of the mid-Atlantic completely unreported in this respect.

A few general remarks on the practical utilization of aerological data in transatlantic flight forecasting are in order if the difficulties raised by its absence are to be appreciated. The author's experience has led him to the conclusion that in our present state of knowledge of the mechanics of atmospheric circulations, and with the limited amount of aerological data which will probably be available from the Atlantic for some years to come, the immediate practical needs of transoceanic flight forecasting really require as a minimum three standard charts: namely (1) the usual upper level wind charts, (2) adiabatic diagrams of the individual temperature-humidity soundings, and (3) upper level pressure maps, especially at the 10,000 foot level. Of course, forecasting research must make use of isentropic analysis and other modern tools of synoptic meteorology which can scarcely be carried out by a routine forecast service.

The principal flight forecast uses of each of the above three standard charts may be summarized essentially as follows:

(1) The upper level wind charts. The obvious merit of these charts is that they give the actually observed instantaneous distribution of winds at a number of upper levels, usually from 1000 to 14,000 feet above sea level. Evidently on the assumption of the continuance of existing conditions, such upper wind charts serve as an excellent basis for estimating head winds, and for selecting optimum flying elevations along the route. Unfortunately, however, this simple representation of the observed wind field aloft does not lend itself nearly as effectively to forecasting the changes in the wind field and the general weather conditions during the forecast period as do the upper level pressure maps, supplemented by the wind observations at the corresponding elevations.

(2) The upper level pressure maps. These maps may be prepared for a number of elevations, but the author's experience has led him to conclude that the 10,000 foot level is best adapted for general usefulness in forecasting. In cases of insufficient pressure observations the upper wind observations for the same level are of assistance in drawing the isobars, and they should be plotted on the map in any case. The upper level pressure map is very useful for the type of forecasting under consideration. In the absence of direct observations of the winds aloft, a condition which inevitably will obtain frequently over the oceans in middle latitudes because of the prevalence of low clouds, this map offers the only possibility of a direct determination of the upper winds. Furthermore, the drawing of isobars aloft furnishes a much more complete, precise, and continuous picture of the state of the motion of the upper atmosphere than do scattered observations of the upper winds. Consequently, the upper level pressure map is much better adapted to a precise estimate of the changing state of motion than are upper

winds charts, hence its usefulness in forecasting the winds aloft. In the author's experience it has been found to be especially useful under the following synoptic conditions:

(a) In determining the breakdown and disappearance of deep persistent quasi-stationary centers of cyclonic activity which may persist in a given locality for weeks at a time. These disturbed areas and the nature of their large-scale circulation is much more clearly shown in the wind and pressure field aloft than at the surface. Furthermore, the first indications of the final breakdown and decay of such a system is to be seen sooner and more clearly aloft than at the surface.

(b) In estimating the perseverance and termination of a certain trend of movement and development of lows in a certain large area on the map. This movement and tendency to develop in a certain region, when it persists, is definitely associated with a certain stationary upper level flow pattern, which may persist for days or weeks. The first and clearest indication of the termination of such a régime, and the establishment of a new régime of cyclonic behavior will be found in the larger features of the pressure distribution aloft. Changes of this kind, and the closely related type of change noted in the paragraph above, must be foreseen if upper winds over a large area, such as the Atlantic ocean, are to be forecast two or three days ahead with any success.

(c) In estimating the direction and speed of motion of Tropical disturbances. During half of the year occassional severe tropical storms move northward through the Atlantic. Because such storms are usually changing their direction and speed of motion as they come up to middle latitudes, they frequently present a serious forecasting problem. However, their motion usually agrees with that of the winds aloft in the region through which they are moving. Probably the air flow at the 10,000 foot level as shown by that pressure map offers the best possible means by which to forecast the motion of such storms.

(3) The adiabatic diagrams of the individual temperature-humidity soundings. Such diagrams indicate the degree of stability or instability existing in the atmosphere. They are especially useful in estimating the possibility of shower activity and the general state of turbulence of the different air masses appearing on the surface map, and the probable results of frontal interaction between the air masses. For winter transatlantic flight forecasting these diagrams are particularly useful in connection with the forecasting of heavy icing. The heaviest icing occurs in saturated air in the first kilometer or two above the 0°C. isotherm, when rapid cooling (heavy condensation) is in progress. This condition occurs locally in the strong convective shower activity of unstable maritime polar air, and generally where a moist warm air mass is undergoing active frontal lifting. The first, or convective shower type of icing, can usually be avoided by proper flying on the part of the pilot. The second, or warm front type, may be very difficult to avoid when it occurs at a low elevation, for freezing temperatures, fog, and freezing rain may extend down to the ocean surface. However, over most of the Atlantic where winter flying is likely to be routed the ocean surface is too warm to permit the occurrence of warm front icing at very low altitudes. But it is obvious that direct information of the temperature and humidity conditions aloft are needed to forecast accurately the occurrence and location of heavy icing conditions. For this purpose the adiabatic diagrams of the individual temperature-humidity soundings are ideally suited.

On the basis of the above discussion one may appreciate the disadvantage at which the forecaster works when he must prepare transatlantic aviation forecasts without the benefit of any aerological data from the Atlantic, such as was frequently the case during the American Export Airlines survey flight period last summer. In the first place, the general forecast must suffer considerably. As pointed out above, the larger features of the circulation régime which control the general pattern of cyclonic activity, including the movement of disturbances of tropical origin, are observed more directly and clearly at upper levels than at the ground. Consequently in the absence of the upper level wind and pressure maps the forecaster is at a considerable disadvantage, both in estimating correctly the existing state of motion of the atmosphere aloft, and even more in predicting accurately important changes in that state which may be imminent. This is particularly important for forecasts having a range of two or three days.

The forecaster will be at a particular disadvantage in his estimation of winds aloft (the headwinds along the flight route). The only thing left for him to do is to estimate the winds aloft on the basis of the observed surface winds and his prediction of change in surface winds. In regions of general stability of atmospheric conditions, notably in subtropical latitudes, this method may be fairly successful, when the forecaster has acquired considerable experience in forecasting for a region where it has been possible for him to check on the verification of his forecasts. But with the rapidly changing conditions of middle latitudes, especially during the cold season when horizontal temperature gradients become extreme and change so rapidly both in direction and steepness, any such method of estimating winds aloft will be highly unsatisfactory, frequently leading to serious errors. This is shown repeatedly by actual upper wind observations in middle latitudes, which so often depart radically and surprisingly from

the surface conditions. If enough were known about the free air temperature distribution, these surprising variations of the winds aloft could be anticipated (*i.e.*, upper level pressure maps could be computed), but without temperature and humidity soundings it is possible only to speculate about the temperatures of the free atmosphere. Even the same air mass types show wide variations in their temperature distribution from one occurrence to the next. Frequently the transitional air masses in middle latitudes are so indistinct in their characteristics, and such mixing of air masses takes place as a result of horizontal turbulent mixing, that in many cases it is not even possible to say whether the air mass in a given region is more tropical or polar in origin. Consequently, it often happens in middle latitudes, especially in the winter, that one cannot possibly reach definite conclusions about either the temperature distribution in the free atmosphere or the winds aloft without aerological observations. Frequent serious mistakes will inevitably follow.

From studying the weather forecasts, especially those of winds aloft, which were issued to the flight officers by the foreign meteorological offices during the survey flights last summer, it was frequently evident that they represented guesses based only on the assumption of the prevalence of the surface pressure gradient direction from the ground up, with a slight increase of velocity at high levels. Little attempt seemed to have been made to forecast any change in the existing conditions, nor was there any evidence that pilot balloon data from the United States had been available or consulted. And yet some of those forecasts included estimates of winds up to 12,000 feet, all the way to New York, which showed little relation either to the conditions existing at the time the forecast was made, as shown by U.S. pilot balloon observations, nor to later developments. The author feels that in many such cases no forecast at all is preferable to a guess of this kind. And this happened in summer. In winter the condition is infinitely more difficult to forecast and more serious in its consequences.

Finally, the same sort of objection holds against forecasts of icing conditions along the flight route in the absence of aerological data. A forecast of heavy icing requires information as to the vertical moisture distribution, the height of the 0°C. isotherm, the temperature lapse rate near and above that level, and the possibility of vertical motion, either convective or frontal. These conditions may be anticipated to a certain extent from a consideration of ocean surface temperature, the air mass type present, and the possibility of frontal action. But the forecast will certainly suffer greatly in precision and correctness without the assistance of aerological data. As already pointed out, there is considerable variation of these conditions from one occurrence to another, even of the same air mass type, at the same position and same seasons.

The icing problem, of course, did not arise last summer. Heavy icing at low levels, in the north Atlantic, will probably be restricted in its occurrence to the period January–March, and then, fortunately, only to the cold water zone off our northeast coast and the Canadian Maritime Provinces. Probably the only type which will be encountered at low levels even at the western end of winter transatlantic flight routes will be the less serious convective type characteristic of fresh maritime polar air masses. The more serious warm front type, insofar as it occurs at low altitudes over the open sea, will be restricted to the coldest coastal waters mostly north of New York.

Much more might be said concerning the disadvantages to the forecaster of transoceanic flight weather in not having aerological data from over the ocean, but the above remarks should suffice to indicate the nature of the problem.

Book Review

(*Continued from page 234*)

values of such systems, and a remark is made on the relation between this procedure and the approach through matrix theory.

The next chapter applies other mathematical methods to the same problems and deals with the application of Fourier series to structures. The energy method of *Rayleigh-Ritz* is discussed in detail. Chapter IX is a very short and simple exposition of the notion of impedance in mechanical and electrical systems and is entitled "Complex Representation of Periodic Phenomena."

Chapter X, "Operational Calculus," is one of the more difficult ones in the book and gives an exposition of that subject with many applications to the transients in mechanical as well as in electrical setups. It starts very aptly with one of the familiar salty quotations of *Oliver Heaviside*, thus making it clear at the outset that this great engineer was the originator of the operational calculus, a fact which is rather minimized by several modern writers on the subject who have recently discovered that the method really was invented by *Laplace*, a century before *Heaviside*.

The closing chapter in the book deals with the "Calculus of Finite Differences" and is illustrated with several interesting problems such as the torsional vibration of an engine with equal cylinders, the voltage distribution along a string of identical electrical insulators, the reactions of a beam on many equidistant supports, and the properties of electrical and mechanical wave filters.

The senior author of this work needs no introduction in the pages of this Journal; his junior partner is assistant professor at Columbia University. East is East and West is West, and the meeting of the two has produced a very readable book.

J. P. Den Hartog
Harvard University

Magnesium for Aircraft Construction

EMERSON W. CONLON

University of Michigan

Introduction

THE use of magnesium alloy as a material for aircraft construction has increased rapidly in the last few years. Castings and forgings are in common use, and a small amount of sheet and extruded stock is being used for cowlings, fairings, and interior furnishings. Little attention, however, has been paid to the possibility of using magnesium for the main structure. It is likely that most designers feel that the use of magnesium alloy in the conventional semimonocoque construction offers too many difficulties from the corrosion standpoint. In reality, magnesium alloy sheet may be successfully used except when subject to frequent immersion in sea water.

The Bureau of Standards report[1] on five-year atmospheric exposure tests at Coco Solo states that, "Magnesium panels were in unexpectedly excellent condition. . . . . It may be concluded that magnesium alloy could doubtlessly be used successfully for prolonged periods in the tropics, particularly if occasional inspection and repair on the paint coating were possible."

This paper deals with the possibility of substituting magnesium alloy for aluminum alloy in certain types of airplane structures, thereby saving weight, and/or decreasing the cost of production. It gives the results of static tests on a monocoque magnesium tail surface and several sheet-stringer panel tests, and indicates the research which must be done before the manufacturer is warranted in adopting such material for production.

Buckling of Flat and Curved Sheet

Mechanical Properties

Alloy	Modulus of Elasticity	Weight lbs. per cu. in.
Aluminum	10,300,000	0.101
Magnesium	6,500,000	0.064

Flat Sheet

Magnesium and aluminum alloy sheets under the same load P, keeping a and b constant, are compared.* (See Fig. 1.)

$$
\begin{aligned}
P_1 &= P_2 \\
P &= K_c E(t/b)^2 bt \\
E_1(t_1/b)^2 bt_1 &= E_2(t_2/b)^2 bt_2 \\
t_2/t_1 &= \sqrt[3]{E_1/E_2} = 1.166 \\
\frac{W_2}{W_1} &= \frac{(t_2)(0.064)}{(t_1)(0.101)} = 0.74
\end{aligned}
$$

where W is the weight of the sheet. This demonstrates a weight saving of 26 percent.

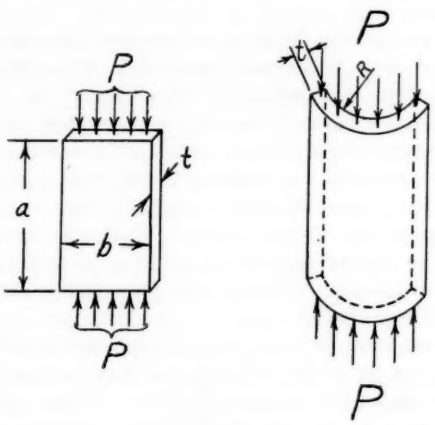

Fig. 1.

Curved Sheet

Assuming that, for a curved sheet,

$$
\begin{aligned}
P &= \frac{KE}{R/t}\, bt \\
t_2/t_1 &= \sqrt{E_1/E_2} = 1.26 \\
\frac{W_2}{W_1} &= \frac{t_2(0.064)}{t_1(0.101)} = 0.80
\end{aligned}
$$

which is a weight saving of 20 percent.

To the airplane designer the above calculations signify that the substitution of magnesium alloy for aluminum alloy sheet in a pure monocoque structure should result in a weight saving of from 20 to 26 percent. These calculations further suggest the possibility of substituting a pure monocoque structure for a semimonocoque structure and obtaining a marked decrease in cost of production by utilizing the simpler structure which has no stringers. Such a procedure should be practical for tail surfaces.

Presented at the Structures Session, Eighth Annual Meeting, I.Ae.S., New York, January 25, 1940.

* Subscript 1 refers to aluminum alloy, and 2 refers to magnesium alloy.

Static Test of Magnesium Monocoque Tail Surface

To test the feasibility of a magnesium monocoque tail surface the author designed the fin shown in Figs. 2 and 3, and it was constructed through the cooperation of the American Magnesium Corporation. At the

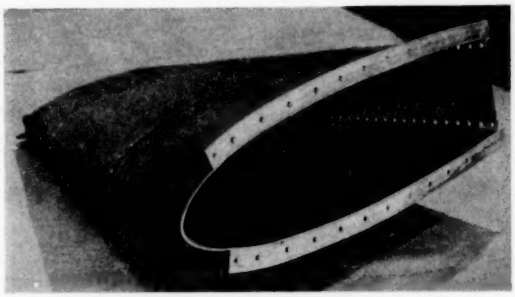

Fig 2.

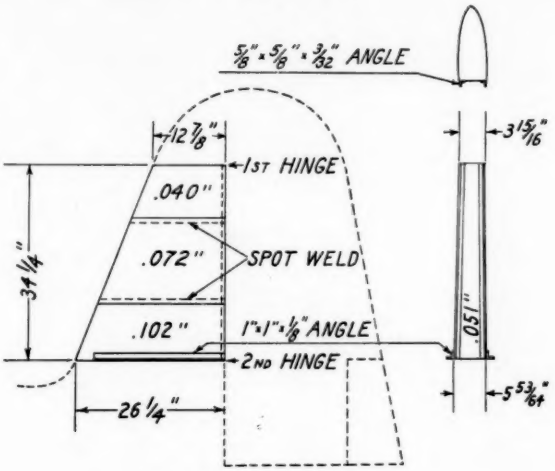

Fig. 3. Magnesium alloy fin.

suggestion of the Army Air Corps, the fin was tested at Wright Field, and full details are given in reference 2. The following characteristics show that it was satisfactory from the strength-weight standpoint.

Characteristics

Design loading = 190 lbs. per ft.^{2} (Balancing Tail Load Distribution)
Ultimate test loading = 342 lbs. per ft.^{2}
Area = 4.65 ft.^{2}
Weight = 9.38 lbs.
Weight/Area = 2.02 lbs. per ft.^{2}

Due to lack of information on the allowable stresses, the structure was over-strength and correspondingly over-weight. The shear lag, as determined from the distribution of stresses, is interesting in that it shows how the low shear modulus of magnesium may be utilized.

Stress Distribution

The distribution of the compressive stress was determined midway between the tip and the root, with a concentrated load applied at the elastic center of the tip section.

Huggenberger gages were mounted $2^1/_2$ in. apart and the stresses determined at each point on three planes 45° apart, in the manner suggested in reference 6. The principal stress was determined by the method given in reference 5. The results are plotted in Fig. 4.

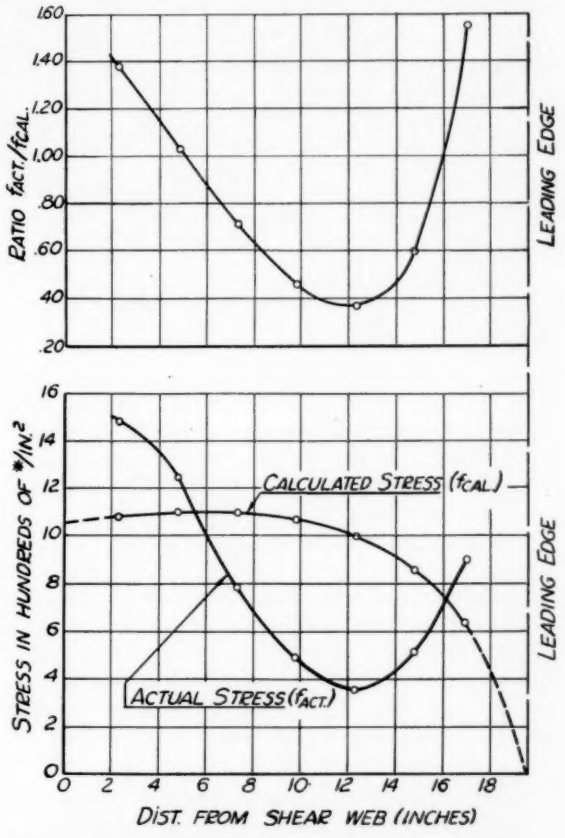

Fig. 4. Stress distribution monocoque fin. Station 17 inches from base.

The curve of the ratio of calculated stress, based upon the beam formula $f = Mc/I$, to the actual stress is of particular interest.

It will be noted that due to shear lag, the compression stress midway between the leading and trailing edges is only 50 percent of the calculated stress, and near the leading edge and rear shear web is 140 percent of the calculated stress. This is particularly advantageous since the allowed stress is greatest at the point where the actual stress is greatest.

At failure, the relatively flat portion of the sheet buckled inward, or "oil canned." (See Fig. 5.) In this case the allowable stress can be approximately calculated by assuming the skin, in the section which

is only slightly curved, as a flat, simply supported sheet, and the actual stress approximates 50 percent of the calculated.

A static test, which applies the load on one side only, is conservative. The compression side buckles inward and under flight conditions there is a normal force on this side acting outward, which opposes the inward buckling of the sheet.

Although the fin held the loading of 342 lbs. per ft.^{2} the compression side was buckled inward to such an extent that it appeared unlikely that it could withstand any increase in load. When the load was partially removed there was a loud report and the fin returned to its normal shape, showing that it was an elastic failure.

Vibration Test

After the static test the fin was vibrated for 20 hours with no sign of failure either in the sheet or the spot welds.

Semimonocoque Structures

Due to its much wider use, the semimonocoque structure is of more interest to the aeronautical engineer than the pure monocoque structure. The allowable stress for this type of structure is usually determined by sheet-stringer panel tests. When attempting to calculate the allowable stress of the sheet-stringer panels, local failure and torsional instability of the stringer must be considered as well as long and short column failure.

If the extrusion is considered as made up of curved and flat sheet and that local failure is the buckling of one of these sheets, then the discussion of the buckling indicates that from the standpoint of local failure the substitution of magnesium for aluminum alloy would result in a weight saving of from 20 to 26 percent.

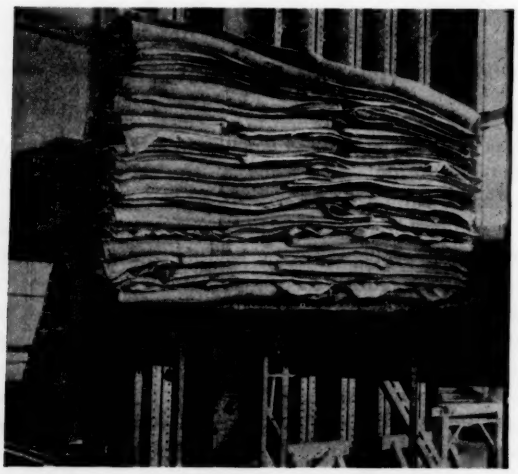

Fig. 5.

In a comparison of the mechanical properties of magnesium and aluminum alloy, the low compression yield strength as well as the low modulus of elasticity is noticeable. A theoretical comparison of the strength of aluminum and magnesium alloy becomes rather complicated and the results of a few panel tests are more enlightening.

Sheet Stringer Panel Tests

Experience has proved that even when considering only the most efficient sections, the allowable stress for extrusions is dependent upon the area. Fig. 6 shows three 24ST dural bulb angles varying in area from 0.068 in.^{2} to 0.229 in.^{2} and in allowable stress from 30,800 lbs. per in.^{2} to 38,400 lbs. per in.^{2}. To compare

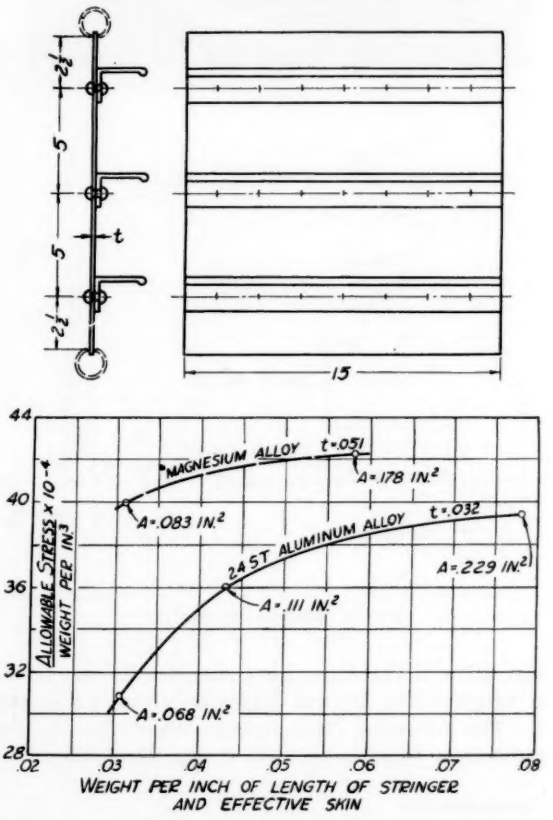

Fig. 6. 15 inch sheet-stringer panel test. A = area of bulb angle. The magnesium alloy data were furnished through the courtesy of Dowmetal Division of the Dow Chemical Co.

bulb angles of different materials it is necessary to consider the allowable loads for bulb angles of the same weight. Hence, Weight per Unit Length, rather than area, and Allowable Stress/Weight per in.^{3} were used as abscissa and ordinate, respectively, rather than allowable stress. It should be noted that the product of abscissa and ordinate is the load carried by the specimen. Hence, the ratio of the ordinates for two angles of the same weight per unit length is the ratio

of the allowable loads and a true comparison of their efficiency.

About thirty magnesium alloy sheet-stringer panel tests have been made, which are relatively few compared with the hundreds of tests made on aluminum alloy panels, but the two tests shown in Fig. 6 indicate the possibilities of saving weight through the use of magnesium alloy. These tests indicate that bulb angles which are satisfactory in 24ST aluminum alloy will not be satisfactory for magnesium alloy, and that the b/t ratio of the sides should be decreased and the diameter of the bulb increased.

Joints

From a strength standpoint, joints may be formed by riveting, spot welding, torch or butt welding.

Formerly, riveted joints using 55S cold-driven rivets have been recommended. However, very recently the American Magnesium Corporation has decided to advocate the exclusive use of 56S rivets, screws, nuts, and washers. It is understood that the ultimate shear stress for this material is approximately the same as the 55S alloy. When joining different magnesium alloys, or magnesium, with dissimilar metals the faying surface must be adequately insulated and care exercised in the proper choice of materials. References 3 and 4 give the best information to date. The increased thickness of magnesium sheet, as compared with aluminum alloy, simplifies the problem of flush riveting and the ease with which it may be welded should enable the designer to obtain the smooth surface so essential to high speeds.

Spot welds made with copper electrodes are subject to rapid corrosion. It is believed that this is due to the infiltration of copper, and that some other material for the tip of the electrodes will prove satisfactory. Chemical purity of the magnesium and alloying elements has been found to be of extreme importance from the standpoint of corrosion resistance.

Alloys and Surface Protection

It is beyond the scope of this paper to go into a detailed discussion of the various alloys and methods of surface protection. Both are continually being improved. It is sufficient to note that the newer alloys are very promising and that satisfactory paint schedules have been determined which may be applied without the use of expensive apparatus.

Available Supply

Last year, about 6,000,000 pounds of magnesium, as a raw material, were produced by The Dow Chemical Company, and for the coming year the output will be doubled. The American Magnesium Corporation and The Dow Chemical Company are the main producers of magnesium alloys in the various forms. The supply is limited only by the size of the manufacturer's plant and availability of electric power.

Conclusion

The present status of magnesium as a material for aircraft construction is similar to that of aluminum in about 1922, and the material is going through the same stages of development. Of the new alloys that are constantly being introduced, the designer should consider only those alloys rated *A* or *B* by the producer, as regards corrosion resistance, and alloys with low elongation as compared with aluminum alloys should be avoided.

Static tests referred to in this paper prove that magnesium alloys are satisfactory from a strength-weight standpoint, although much more research must be done to determine the most efficient forms, particularly extrusion and corrugation.

Full-scale static and service tests on wings, fuselages, or tail surfaces must be made to definitely prove that the material and method of surface protection are satisfactory under actual service conditions.

The practice of some manufacturers to use magnesium alloy sheet for fairings and cowlings appears to be a hard way of learning how to fabricate the material. These parts are difficult to form in any material, and strength is a minor consideration. It would seem more practical to first use magnesium sheet where little forming is required and where the high buckling strength is important, such as the covering of a wing or fuselage.

It appears to the author that the stamped butt-welded or cast wing and fuselage may offer as much possibility for low-cost quantity production as any of the various plastics which have recently been suggested.

References

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[2] To be published as an Air Corps Report.

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Wing Frequencies of Multi-Engine Monoplanes

R. H. MILLER

The Glenn L. Martin Company

ABSTRACT

The effects of elastically suspended engines on the natural frequencies of a wing are determined and the torsional frequencies analysed by means of an equivalent spring-mass system. This analysis is then correlated with test data obtained on a ground vibration test.

THE importance of the torsional rigidity and mass moment of inertia of a wing in the determination of its critical flutter speed is clearly demonstrated by the two-dimensional theory of aerodynamic instability. To date the resonant frequencies have been taken as sufficient criterion for the wing's mass and stiffness characteristics but, though this is justified in the case of a single engine ship, elastically suspended engines carried in the wing have the effect of introducing other torsion modes not of direct interest in the prediction of flutter speeds. It is proposed to examine these modes both analytically and from test data obtained on a ground vibration test.

The bending frequency of the wing is easily calculated by equating the kinetic and potential energies under an assumed dynamic deflection curve in the usual manner. Fig. 2 shows the deflection curve for this frequency with the calculated curve and test points. The bending modes are determined from the condition that the summation of the acceleration forces, as determined by the assumed deflection curve, must be zero for the whole airplane.[1] Thus, if a deflection curve of the form $y = f(x)$ is assumed where the y and x axes are, respectively, a vertical line through the center line of the ship and a line tangent to the deflection curve at the center line of the ship and if δ is the height above the x axis of a line drawn through the nodes, then

$$\Sigma(y - \delta)m = 0, \text{ or } \delta = \Sigma ym/\Sigma m$$

m being the increment mass along the span.

The nodes for the fundamental bending frequency will be found to occur very near the engines on a twin engine ship and it may therefore be assumed that the suspended mass of the engines will have little influence on this frequency.

However, this assumption is not necessarily true for the fundamental torsion mode as due to the high pitching moment of inertia of the fuselage relative to the wing, the torsion node will occur considerably inboard of the engine. This node cannot be calculated readily by the method outlined above for the bending node, but may be determined by equating the frequency of the portion of the wing inboard of the node to that of the outboard portion. Once this condition has been satisfied only the portion outboard of the node need be considered.

In order to determine the effect of the engines on the torsional frequency, the wing will be replaced from the node out by the equivalent spring-mass system shown in Fig. 1, which has been set up to represent only pure torsional motion of the wing about the elastic axis. Since the present trend is to "de-couple" the

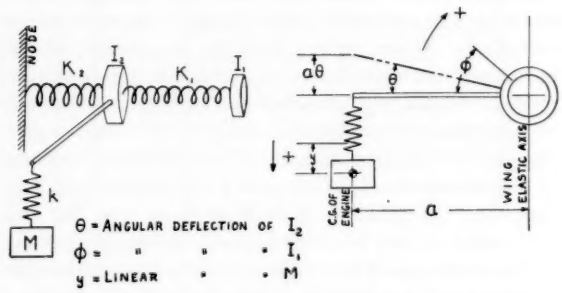

FIG. 1. Equivalent system for wing-engine combination.

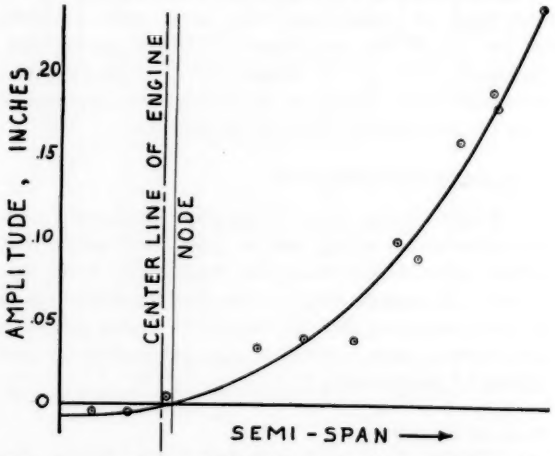

FIG. 2. Amplitude distribution at bending resonance frequency.

pitching and vertical motions of the engine itself, the suspended mass, M, of the engine will be assumed to have only vertical freedom represented by a spring k, the stiffness of the engine mount and its supporting structure. K_2 then represents the average torsional stiffness of the wing between the node and the center

Received September 13, 1939.

line of engines, I_2 is one-third the mass moment of inertia of that portion of the wing and its contents and K_1 and I_1 are determined from the calculated torsional frequency of the outer panel.

The following equations of motion for the system may now be set up using the coordinate system shown in Fig. 1.

Vertical forces on M: $M\frac{d^2y}{dt^2} + k(a\theta + y) = 0$

Moments acting on I_2: $I_1\frac{d^2\phi}{dt^2} + K_1(\phi - \theta) = 0$

Moments on complete system outboard of node:

$$I_2\frac{d^2\theta}{dt^2} + K_2\theta + k(a\theta + y)a - K_1(\phi - \theta) = 0$$

Solving these differential equations by the harmonic substitutions

$$y = y_0 \sin \omega t;\ \theta = \theta_0 \sin \omega t;\ \phi = \theta_0 \sin \omega t$$

reduces them to the algebraic form

$$-M\omega^2 y_0 + k(a\theta_0 + y_0) = 0 \quad (1)$$
$$-I_1\omega^2\phi_0 + K_1(\phi_0 - \theta_0) = 0 \quad (2)$$
$$-I_2\omega^2\theta_0 + K_2\theta_0 + k(a\theta_0 + y_0)a - K_1(\phi_0 - \theta_0) = 0 \quad (3)$$

which may be expressed in determinant form as follows:

$$\begin{vmatrix} -M\omega^2 + k & 0 & ka \\ 0 & -I\omega^2 + K_1 & -K_1 \\ ka & -K_1 & -I_2\omega^2 + K_2 + ka^2 + K_1 \end{vmatrix} = 0$$

Equating the determinant to zero and expanding gives the following cubic for ω^2, the frequency squared:

$$I_1I_2M\omega^6 - \omega^4(I_1K_2M + I_1Mka^2 + I_1K_1M + MK_1I_2 + I_1I_2K) + \omega^2(I_1kK_2 + K_1I_1k + MK_1K_2 + MK_1ka^2 + kK_1I_2) - kK_1K_2 = 0$$

The solution of this equation yields three frequencies whose modes may be determined from the amplitude ratios. Thus, from Eq. (1)

$$\frac{a\theta_0}{y_0} = \frac{M\omega^2}{k} - 1 \quad (4)$$

But the vertical frequency of the engine is given by $\omega_E = \sqrt{k/M}$ whence Eq. (4) may be rewritten

$$\frac{a\theta_0}{y_0} = \frac{\omega^2}{\omega_E^2} - 1$$

From Eq. (2)

$$\frac{\theta_0}{\phi_0} = -\frac{I_1\omega^2}{K_1} + 1 \quad (5)$$

and since the frequency of the outer panel is given by $\omega_1 = \sqrt{K_1/I_1}$ Eq. (5) may be written

$$\theta_0/\phi_0 = 1 - \omega^2/\omega_1^2$$

From Eqs. (4) and (5) it will be found that of the three fundamental modes the first corresponds to a low frequency involving considerable twist of the center panel, very little additional twist of the outer panel and considerable engine motion; the second mode, usually about two or three times higher than the first, corresponds to a frequency very close to that of the outer panel alone. In this mode the twist of the center panel and the engine motion is negligible. The third mode corresponds to a relatively high frequency involving opposite twists of center and outer panels and is of no practical interest.

The actual torsional deflection along the span during the two lower coupled frequencies may be determined by working back through the Stodola[2] method for determining natural frequencies. This was done in the case of one airplane when it was still in the design stage and the frequencies and modes checked later by tests on the finished model. Figs. 3 and 4 show the two modes for a full cantilever twin engine monoplane with the predicted deflection curves and the points as found from test. The higher frequency in this case was 690 c.p.m. and the lower 400 c.p.m., the calculated values being, respectively, 680 c.p.m. and 370 c.p.m.

Since the flutter speed of an airplane varies approximately as the torsional frequency, all other conditions

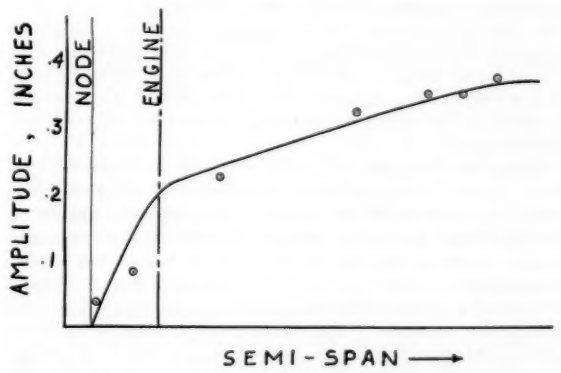

FIG. 3. Amplitude distribution at first wing-torsion resonance.

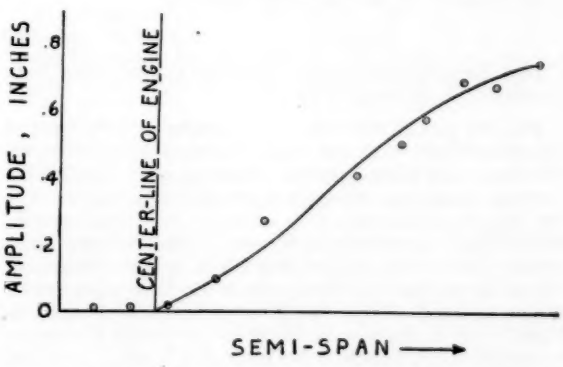

FIG. 4. Amplitude distribution at second wing-torsion resonance.

remaining the same, the lowest fundamental mode would indicate the possibility of a critical velocity appreciably less than that associated with the second fundamental mode, which closely approximates the frequency generally used in calculations. Past experience indicates that the higher mode is critical in flight but a rigorous proof of this is beyond the scope of the present paper. A possible explanation may be found from an examination of the torsional deflection curve for the wing during the lowest mode (see Fig. 3) where it will be noted that considerable twist of the portion of the wing inboard of the engine, whose center of gravity is usually well forward of the leading edge of the wing, occurs. This tends to bring the "weighted" center of gravity for the whole wing further forward and may well raise the critical velocity, which is greatly effected by a slight change in center of gravity location, above that associated with the higher mode. However, the dissimilarity between the elastic curves of the wing at its resonant bending and lowest torsional frequency (see Figs. 2 and 3) precludes the treatment of coupling between these two motions by the available two-dimensional flutter theory.

References

[1] Nagel, Felix, *Flügelschwingungen in stationären Luftstrom*, Luftfahrtforschung Band 3, Heft 5, page 113, May 5, 1929.

[2] Den Hartog, J. P., *Mechanical Vibrations*, page 174; McGraw-Hill, New York, 1934.

Book Reviews

Safety in the Operation of Air Transportation, by Jerome Lederer; A James Jackson Cabot Professorship Lecture, Norwich University, Northfield, Vermont; 69 pages, $0.50.

It would be difficult to find anyone who has made such a continuous and intensive study of safety in the air as has Jerome Lederer. An engineer of recognized ability, a member of many engineering societies, Secretary of the Aeronautical Section of the National Safety Council, and author of many technical papers, he gives, in this lecture the results of his practical experience as engineer for a group of insurance companies.

Again the foresight of Dr. Godfrey L. Cabot of Boston in endowing the James Jackson Cabot Lectures in memory of his son has made possible the presentation of a well-considered summary of an all-important element in air transportation.

The author modestly states that the lecture is for the student rather than for the specialist. However, all who are interested in safety in air transport operation should read this excellent presentation.

The lecture concludes with an apt summary: "The factors that have brought airline safety to its present state are good equipment, kept constantly airworthy; conscientious, experienced, and intelligent personnel, directed by conservative executive policy; thorough training of new personnel before they assume responsibility; constant checking of work being done; alertness in foreseeing the possibilities of accidents and preventing them before they can occur; efficient cooperation between operating units; and cooperation with the aviation industry by various governmental departments such as the Weather Bureau, the C.A.A., the N.A.C.A., the Post Office Department, the Federal Radio Commission, and the military agencies."

How They Fly, by James Gardner; Country Life, Ltd., London, 1939; 32 pages, 3s. 6d.

The best part of this book is that dealing with the flight of insects and birds. This lays a good foundation for a brief sketch of curious early flying machines. However, when "Cauldrons," "Dornias," and "Adas" pass in review there is a temptation to feel that the author was a little careless in his textual research. If one wishes to read (not too critically) a brief, well illustrated, popular review of the progress man has made in his conquest of the air he may find much of interest in this book, which had its inspiration in an exhibition held at Shell Mex House in London in 1939.

Air Workers, Alice V. Keliher, Editor; Harper and Brothers, New York, 1939; 56 pages.

The opportunities offered by the aircraft and air transport industries are shown pictorially and graphically in this attractively edited picture book. By a careful selection of illustrations the aspirant to a job in aviation is given some idea of the pay, hours, and types of work required. The text is written for youthful searches for vocational guidance and supplements the pictorial presentation. It is a book which can arouse interest in boys and young men and give them some criterion of selection in applying for a job or planning a career in aviation.

Sanabria's Air Post Catalogue; Nicolas Sanabria, Inc., New York, 1940; 714 pages, $2.50 (cloth bound), $5.00 (de luxe edition).

The tenth edition of this invaluable book for philatelists is again an all-embracing catalogue of the Air Post Stamps of the world. While it is primarily compiled to give stamp collectors the prices and quantities of all known issues, the several thousand illustrations of stamps of all countries make the book literally a pictorial history of aeronautics, along with portraits of famous persons who have played a part in the development of flying. It is not too much to say that it would be easy to illustrate a history of aeronautics from the engravings on the stamps.

Hell in the Heavens, by A. G. J. Whitehouse; W. & R. Chambers, Ltd., London; 262 pages.

This is the story of a P.B.O. (poor bloody observer) with the Royal Flying Corps during the war. Whitehouse is an American who enlisted in the British Army, became a gunner and transferred to the R.F.C. He has a gift for vivid description and his account of life as an observer will give any young man, who is ambitious to follow military aviation, an insight into what air war is really like. He kept a diary and from it has recalled the adventurous experiences he had as a private in bringing down enemy aircraft.

He writes "I have never met a *real* wartime pilot who considered himself superior to his observer, but I have run into plenty who frankly and sincerely declare that the gunners and observers aboard the two-seaters did more to break the spell of the Fokker Scourge than any other aerial figure on the front."

The P.B.O.'s deserve recognition which they have never received; this book tells of the hardships endured by these courageous but little publicized airmen.

Institute Notes

Meetings of the Institute

Annual Summer Meeting

The Second Annual Summer Meeting of the Institute will be held in Pasadena, California, on Monday, Tuesday, and Wednesday, June 24–26. The Annual Summer Meetings were inaugurated by the meeting held last June at the California Institute of Technology. Although this was called the "Pacific Coast Annual Meeting," it was thought best to change the name this year to obviate any impression that the meeting is sectional. Those who attended the 1939 meeting will remember it as one of the most successful that the Institute has held.

The technical sessions of the 1940 meeting are being planned to cover a wide range of important subjects. The tentative program includes papers on aerodynamics, flight testing, meteorology, vibration and flutter, and physiology. The meeting will be concluded with a special evening event, the details of which are being guarded with much secrecy.

The members of the Committee on Arrangements for the meeting are Dr. A. E. Lombard, Jr. (Chairman), W. W. Beman, J. R. Goldstein, E. J. Horkey, Dr. A. L. Klein, R. W. Palmer, E. A. Peterman, and W. C. Rockefeller.

Institute Session at the A.A.A.S. Summer Meeting

The Institute will hold a one-day session on Air Transport and high altitude problems on Friday, June 21, at the Summer Meeting of the American Association for the Advancement of Science in Seattle, Washington. At this meeting the Institute will make the formal presentation of the Musick Memorial Trophy.

The date of this session in Seattle was arranged to facilitate the plans of those who wish to go directly from there to attend the Institute Annual Summer Meeting in Pasadena without loss of time.

Robert J. Minshall to Receive Musick Memorial Trophy

The presentation of the Musick Memorial Trophy at the Institute session of the A.A.A.S. Meeting in Seattle on June 21 will be made to Robert J. Minshall, Vice-President in charge of Engineering, Boeing Aircraft Company. The selection of Mr. Minshall to receive the award for 1940 was announced recently by a committee of citizens of Auckland, New Zealand. This group established the award in 1938 in memory of Captain Edwin Musick and his six companions who were lost in mid-Pacific on the first commercial flight from the United States to New Zealand. It is conferred annually on the individual in the United States or Great Britain who, in the opinion of the committee, makes the most valuable contribution toward the safety of life in the air with especial regard to transoceanic flying. The recipient will have the custody of the trophy for one year and also will receive a miniature replica to keep permanently. Last year the award was given to Arthur Gouge of England, designer of the Short Brothers "Empire" flying boat.

Mr. Minshall, a Fellow of the Institute, was responsible for the engineering and production of the Boeing type Clipper which is used by Pan American Airways on its transatlantic and transpacific routes. He has been selected to receive the Trophy "for his outstanding contribution to the safety of transoceanic air transport through major engineering improvements in large flying boats."

Gifts to the Aeronautical Archives

During the past month numerous additional gifts have been received by the Archives.

Mr. Orville Wright presented nine issues of "The Aeronautical Journal" of various dates from 1909 to 1912 and Major D. H. Kennedy, Honorary Treasurer of the Royal Aeronautical Society, sent two issues for 1917. These will complete the Institute's file of this very valuable Journal.

Other gifts obtained through the R.Ae.S. are a copy of Moedebeck's "Pocket Book of Aeronautics" (1907) sent by its Secretary, Captain J. Laurance Pritchard, and from Mr. J. E. Hodgson, Honorary Librarian, a copy of "The Connoisseur" (1911) containing interesting data on Dr. John Jeffries of Boston, the first American citizen to take an interest in aeronautics and who with Blanchard made the first flight by air across the English Channel.

Col. Charles A. Lindbergh sent the log of his San Diego to New York flight in the Spirit of St. Louis in 1928 and has offered to present other interesting material.

Copies of a "Bibliography on the Selection, Training and Physical Fitness of Aviation Pilots" were received from the author, Dr. Ross A. McFarland, and reprints of papers on aviation medicine were sent by Col. Arnold D. Tuttle.

Mr. John A. Eubank contributed twenty-two periodicals and pamphlets containing articles he has written on aeronautical law.

An "Air Service Medical Manual" and a brochure on aircraft engine installations was received from Mr. E. U. Fairbanks.

Mr. Jerome Lederer donated copies of "The Bulletin" published by Canadian Airways, Ltd.

The books, "Aviation, Its Commercial and Financial Aspects," by R. R. Bennett, "Aircraft Float Design," by H. C. Richardson and "Elements of Aviation," by V. E. Clark, were given by the publishers, The Ronald Press Company.

Newspaper clippings describing the U. S. Army Air Corps Around-the-World Flight in 1924 were sent by Col. William R. Blair.

Mrs. Bella C. Landauer gave an interesting collection of old sheet music containing songs relating to aviation.

An addition to the Archives medallion exhibit was made by Mr. Joseph P. Gavron of Rockefeller Center, Inc., who presented a silver medallion commemorating the Rome-Chicago-New York-Rome flight led by General Balbo in 1933.

Transcontinental & Western Air, Inc., have given the Institite two "Hushatone" radio speakers with which to demonstrate the method by which passengers on modern air transports are enabled to hear radio programs without disturbance to others.

University of Minnesota Bibliography Added to Archives

The Institute appreciates the cooperation of the University of Minnesota in making available their collection of approximately 4000 cards listing over 10,000 bibliographies with references to aerodynamics, general aeronautics, N.A.C.A. reports, books and sources on a long list of subjects. This collection, prepared by the W.P.A. under the direction of the University of Minnesota, has been copied and makes a valuable addition to the Institute's Aeronautical Index.

Student Branches

Massachusetts Institute of Technology. At a meeting on February 28th Dr. William M. Murray presented the Branch Lecture "The Use of Nickel and Nickel Alloys in Aircraft Construction," prepared by J. W. Sands.

University of Michigan. A meeting of the Student Branch was held on February 29th. Dan Grudin, Engineering Council Representative, gave an Engineering Council Report. Following this, Joseph Gwinn, Chief Project Engineer for Bell Aircraft, spoke on "Detail Design." The lecture was very well received by the sixty members and friends attending the meeting.

Catholic University of America. At a meeting on February 21st, Dr. Hugh L. Dryden, Chief of the Mechanics and Sound Division at the National Bureau of Standards, spoke on "Some Experimental Methods in Aerodynamics." During the course of the lecture Dr. Dryden gave an interesting demonstration of the hot-wire anemometer method of determining wind-tunnel turbulence.

Notre Dame University. Robert DeMoss presented the Branch Lecture "Safety from the Ground Up," prepared by Jerome Lederer, at a meeting of the Student Branch on February 29th. Following this, several of the members gave interesting accounts of experiences they have had while flying. Thirty members attended the meeting.

Personnel Opportunities

The Personnel Bureau serves individual members, as well as organizations seeking to employ aeronautical specialists. Any member or organization may have requirements or qualifications listed without charge.

Available

Ensign, U.S.N.R., age 25, 1500 hours, 1100 hours first pilot, 1200 hours twin-engined aircraft; license classes 2S land 4M land and water, 5 land and water and instrument rating. B.S. in Mech. Eng. with Aero. option. Released from active duty July 25, 1940. Address reply to Box 99, Institute of the Aeronautical Sciences.

Changes in Membership

The following changes in the membership of the Institute have occurred since the publication of the previous issue of the Journal.

Elected to MEMBER Grade

Bryan, Guy Lee, Jr., M.C.E.; M.I.Ae.S.; Chief of Structures, Glenn L. Martin Co.

Carry, William James, M.E.; M.I.Ae.S.; Engineer, The B. G. Corp.

Evans, George Dorsey, M.S.E.; M.I.Ae.S.; Assoc. Aero. Engineer, Naval Aircraft Factory.

Griswold, Roger Wolcott, II, Ph.B.; M.I.Ae.S.; Vice-Pres., S. O. S. Syndicate, Inc.

Hambrook, Robert William, M.A.; Hon. Dr. Vocational Educ.; M.I.Ae.S.; Sr. Specialist, Office of Education, Federal Security Agency.

Kearns, Charles Maxwell, Jr., B.S. in E.E.; M.I.Ae.S.; Project Engineer, Hamilton Standard Propellers Div., United Aircraft Corp.

Kinnucan, James William, B.S. in M.E.; M.I.Ae.S.; Chief Engineer, Aircraft Engine Div., Continental Motors Corp.

Littell, Robert Elwood, B.S.; M.I.Ae.S.; Asst. Aero. Engineer, N.A.C.A.

Wood, John Walter, M.Arch.; M.I.Ae.S.; Partner, Poor & Wood, Airport Consultants.

Elected to Industrial Member Grade

Ambrose, Frank Joseph, B.S. & E.; M.I.Ae.S.; Pres., Aviation Institute of New York.

Crane, Richard Teller, M.I.Ae.S.; Pres., Airline Feeder System, Inc.

Thorburn, Donaldson Bride, A.B.; M.I.Ae.S.; Asst. Advertising Mgr. (Aviation), Shell Oil Co.

Elected to Technical Member Grade

Armstrong, William, B.S.; Chief Engineer, Dowty Equipment Corp.

Arnold, James Elwood, M.S.; Instructor, Mech. Engineering, Tulane Univ.

Houston, Robert Raymond, Jr., Aircraft Inspector, Pan American Airways.

Hughes, Francis, Aviation Instrument Research, Henry Hughes & Son Ltd. England.

Sailer, Ernest Rudolf, Stress Analyst, Lockheed Aircraft Corp.

Sawdey, Marshall Douglas, B.S. in Ae.E.; Engineer, Bell Aircraft Corp.

Thomas, Kenneth Funston, M.A.; Development Engineer (Aircraft), SKF Industries, Inc.

Transferred from Student Member to Technical Member Grade

David Herman, Engineer, Pollak Mfg. Co.; Robert W. Huether, Engineer, Lockheed Aircraft Corp.; Murray Kanes, Engineer, Republic Aviation Corp.; Lester G. Kelso, Inspection, Boeing Aircraft Co.; Walter Kleven, Sr., Detail Draftsman, Lockheed Aircraft Corp.; Rolf Kjode, Engineer, Jacob Kjode, A/S, Norway; Neil Lamont, Jr., Weight Engineer, Douglas Aircraft Co.; Herbert C. Langmore, Liaison Engineer, Lockheed, Aircraft Corp.; S. R. Leonard, Jr., Machinist, Oneida Ltd.; R. G. Lindstrom, Draftsman, Glenn L. Martin Co.; Dan A. Logan; Harold Luskin, Aero. Engineer, Douglas Aircraft Co.; Ying Quock Mah; R. B. Marozick, Jr. Aero. Engineer, U.S. Army Air Corps; J. R. McCarthy, Aviation Cadet, U.S. Naval Reserve; G. A. McMahon; Robert M. Miller; James R. Moody, Jr., Flying Cadet, U. S. Army Air Corps; Richard E. Moore; W. H. Moore, Test Engineer, Ranger Engineering Div., Fairchild Engine & Airplane Co.; James L. Murray, Jr. Aero Engineer, N.A.C.A.; H. H. Patton, Stress Analyst, Glenn L. Martin Co.; A. C. Pfister, Technical Staff, Bell Telephone Laboratories, Inc.; F. C. Phillips, Aero. Engineer, Glenn L. Martin Co.; W. Harison Phinizy, Engineer, Lockheed Aircraft Corp.; Jack V. Rich, Weight Engineer, Douglas Aircraft Co.; Robert F. Richter; Perry J. Ritchie, Jr. Aero. Engineer, U.S. Army Air Corps; Joe Rosenberg, Jr.; Oliver B. Rosstead, Jr., Inspector, Curtiss Propeller Div., Curtiss-Wright Corp.; Alexander Satin, Aero. Engineer & Instructor, Curtiss-Wright Technical Inst.; Victor Mead Saudek, Engineer, North American Aviation, Inc.; Thomas H. Scarborough, Jr., Detailer, Lockheed Aircraft Corp.; H. C. Schmidt, Apprentice Engineer, Pan American Airways; K. N. Scholes, Aviation Cadet, U.S. Navy; L. H. Shornick; Max Sokol, Engineer, Brewster Aeronautical Corp.; Joseph E. Stanton, Detailer, El Segundo Div., Douglas Aircraft Co.; Elwyn L. Treat, Jr. Aero Engineer, U.S. Army Air Corps; Wm. J. Underwood; A. W. Vogeley, Jr. Engineer, N.A.C.A.; Leo A. Weiss, Jr., Engineer, U.S. Army Air Corps; H. M. Willson, Agent, American Airlines; Charles Wirth, Draftsman, Glenn L. Martin Co.; Oscar W. Wuerz, Automotive Engineer, Parmelee Motor Fuel Co.

Aeronautical Reviews

These brief reviews of recent articles on aviation subjects are published by the Army Air Corps for the information of its officers, and are printed here each month by permission of the Chief of the Air Corps

Aerodynamics

Recent Progress in Aeronautics. "Progress in Aerodynamics," C. Tilgner, Jr. "Airplane Design Progress," R. M. Mock. "Development in Aircraft Power Plants," C. F. Taylor. "Development in Aviation Accessories," R. P. Lansing. "Aviation Radio Developments," W. P. Hilliard. "Development in Meteorology," A. F. Spilhaus. Annual Progress Report of the Aeronautic Division of the American Society of Mechanical Engineers. *Mechanical Engg.*, February, 1940, pages 111–115.

Recent Investigations of Profile Properties. F. Riegels. Results recently obtained in the construction and calculation of theoretical wing profiles and their pressure distribution are considered. Treatment of the field of flow surrounding the profile is taken up, and experimental research on maximum lift and profile drag with reference to the complicated frictional effect in flow around bodies is described. The construction of profiles having prescribed pressure distribution is discussed. This problem is said to be very important since the behavior of the frictional layer depends greatly on the pressure course on the wing surface and the maximum lift and profile drag are greatly affected by development of the boundary layer. Research on the effect of surface roughness, and on measurements at different Reynolds numbers and in different wind tunnels is also covered. Results of N.A.C.A., British and German research. *Luftwissen*, December, 1939, pages 299–304, 13 illus.

Aircraft Design

Equipment and Tactics for Dive-Bombing. H. F. King. International practice in dive bombing, design of the specialized aircraft required, diving brakes, heavy bombs used, and problems presented by the human element are discussed in great detail. Stages of modern dive-bombing attack are described by a European authority and diagrams illustrate possible dive-bombing approaches under different kinds of weather conditions.

Difficulties in designing dive bombers in regard to structure, aerodynamics, vision, and limited dimensions and landing speeds for carrier operation are reviewed briefly. Selected types of dive bombers from America, England, Germany and Italy are described, including the Curtiss SBC series (Marks 1-4) used by the Naval aircraft carriers. Mention is made of the Brewster XSBA-1, Douglas and Vought dive bombers. One of the most modern dive bombers in the world is said to be Italy's Savoia Marchetti S.M.85 twin-engine high-wing monoplane with trailing-edge flaps hinging through 90° to act as diving brakes. The Junkers Ju.88 high-speed twin-engine bomber is believed to be stressed for delivering diving attacks at a comparatively shallow angle.

Cutaway drawing of the Junkers Ju.87 two-seater dive bomber shows how the single large bomb carried beneath the radiator is swung outboard before release. An American bomb-displacing gear, shown diagrammatically, is believed to be essentially similar to the type used by the U.S. Navy. Drawings are given for the following to provide a comparison in design of dive bombers and to indicate the relative sizes of the projectile carried: Fairey P.4/34, Blackburn Skua, Junkers Ju.87, Hawker Henley, Vought SB2U-1 (V-156), Fokker G.1, Blohm and Voss Ha. 137, P.Z.L. Wilk, Brewster XSBA-1 (Model 138), Curtiss SBC-4 (Helldiver 77), Bell BC.1, Douglas DB-19, Loire-Nieuport LN.40, and Savoia Marchetti SM.85. *Flight* January 25, 1940, pages 78a-78d, 79, 66 illus.

Escort Fighters. H. F. King. First issue—In reference to a previous article by this author and under the above title, an editorial deals with the question of cleaning up the aerodynamic design of escort fighters, arrangements of engines in positions other than on the wings being suggested for reducing drag. With engines placed in tandem, three alternatives appear possible. Engines may be made to drive two propellers in opposite directions, or engines may be placed inside the fuselage but with the propellers mounted outboard, ahead of the leading edge of the wing. Still further drag reduction would be attained by placing the propellers behind the wings. Research on the design, strength and weight of shafting is recommended to the Royal Aircraft Establishment.

Correspondence on another page includes: criticism of the heavy type of escort fighters; question of whether relative losses of the enemy compared with those sustained by British machines will show the heavy escort to be justified; suggestion of two fighters to one bomber; twin engines and contra-propellers; and the author's replies to each.

Second issue—Correspondence from C. R. Barty discusses the question of contra propellers for escort fighters. In editorial comments on the previous article (January 25 issue) it was suggested that (A) contra propellers mean added weight, and that (B) shaft drives be used to propellers located on the wing structure. In the present letter it is suggested that if engines are installed in the fuselage in tandem, the engine mounting should weigh less than that for two separate engines, and modifications necessary are briefly pointed out. Case B is also discussed. *Flight*, February 8, 1940, pages 127–128. See also *Flight*, January 11, 1940, pages 30a–30e, 15 illus.

Problems of Submerged Engine Installations. W. E. Beall and G. E. Emery, Jr., Boeing Aircraft Co. Abstract only of paper presented before the National Aircraft Production Meeting. See page 128, January, 1940, issue of the Journal for abstract of preprint. *S.A.E. Jour.* (*Trans.*), February, 1940, page 68.

Toward Economic Air-Line Equipment. A. F. Bonnalie. Economic worth of the transport airplane. Size, speed, range and utilization for economic operation are considered. Discussion of the paper given by W. F. McGinty is included. *A.S.M.E. Trans.*, January, 1940, pages 1–7, 8 illus., 9 equations.

Military Versatility. H. F. King. As multipurpose military aircraft, twin-engine high-powered airplanes of 9000 to 15,000 lb. weight are proposed which have the speed, maneuverability, range, ceiling, crew accommodation and armament possibilities to suit them for high-speed short- and medium-range bombing, ground attack, tactical and strategical reconnaissance, fighting, and possibly torpedo dropping. Possibilities of the various aircraft for these purposes are discussed in regard to their armament and other equipment, engines, load, and missions for which they can be equipped. *Flight*, January 4, 1940, pages 8a–8d, 9, 20 illus., 1 table.

Pusher Screws—A Trend toward Propellers. Advantages of the pusher-propeller arrangement for the single-seater fighter, answer to the reported criticism that stones thrown up by wheels of the Bell XFM-1 Airacuda damaged its pusher propellers, and a reference to the Focke-Wulf Fw.198, a new German pusher fighter which has been reported over the Western Front. The Fw.198 is a single-seater monoplane in which the pilot sits in a central nacelle in front of the engine, believed to be a Daimler Benz. Tail is held on twin booms attached to the wings outboard of the engines.

Difficulties in adapting radial aircooled, and even inline aircooled, engines to cooling in the pusher position, and redesign of propellers and hub required to get the fullest efficiency of the size and shape of the nacelle at the propeller are mentioned as problems. W. F. Hilton's opinion that tractor propellers on engines in the wings will be impossible if speeds of more than 500 m.p.h. are to be achieved, is quoted. Photograph and general arrangement drawing of the Airacuda are shown. *Aeroplane*, January 12, 1940, pages 51–52, 2 illus.

Rotary-Wing Aircraft. J. A. J. Bennett. Underlying physical principles of rotary-wing aircraft, and current state of knowledge. Relative merits of the helicopter, rotaplane, and gyrodyne are presented. Theoretically, the helicopter is considered the most efficient rotary aircraft owing to its better propulsive efficiency, especially at slow speeds, in spite of its increased structural weight and possibly higher parasite drag. Theoretically also, on account of the steepness of its ascent and its slow vertical descent under power, it can be operated from smaller and more confined areas than any other aircraft. The rotaplane has the advantage of mechanical simplicity and safety and, with the introduction of direct take-off, achieves in practice qualities long sought for in the helicopter.

Flapping and feathering of the rotor blades, direct control about rolling or pitching axis, phase relationships in a sustaining rotary-wing system having flapping blades with controllable periodic variation of pitch angle, and performance of rotary-wing aircraft are discussed in great detail. To be continued. *Aircraft Engg.*, January, 1940, pages 7–9, many equations.

Rudder Control Problems on 4-Engined Airplanes. C. L. Johnson, Lockheed Aircraft Corp. General study made on the problem of directional controllability of a modern four-engine airplane after a failure of one or two engines under take-off conditions. The low-wing four-engine tractor airplane considered has a wing loading between 30 and 40 lb./sq.ft., and a take-off power loading of approximately 8 lb./hp. Airplane is assumed to be equipped with large vertical tail surfaces having a total area of approximately 14 to 16 per cent of wing area, and disposed in an efficient manner such as a triple tail, giving a good combination between directional stability and control. Several factors which have an important bearing on rudder controllability, particularly at take-off speed, are clarified.

Rudder controllability with unsymmetrical power, effect of angle of yaw, flight with two engines inoperative, and effect of design trends are discussed. It is concluded that power and wing loadings are changing in a manner which tends to keep the one-engine-inoperative-controllability problem a constant. For an airplane with 30 lb./sq.ft. wing loading and a 12 lb./b.hp. power loading, ample controllability can be obtained within 2 m.p.h. of the flap-up power-on stall speed by allowing and holding 5° yaw, and, for a four-engine airplane (40 lb./sq.ft. wing loading, and 8 lb./b.hp. power loading) at 7 m.p.h. above power-on stall speed when one outboard engine is inoperative, 5° yaw being used in this case also.

Controllability problem after engine failure on take-off can be solved in the following ways: by increasing vertical tail area by substantial amounts over present design, this requiring increased dihedral for the wing to avoid instability; by arbitrarily holding the airplane on the ground until control speed is reached; when enough power is available as in four-engine airplanes, by coupling symmetrical engines together so that failure of one engine immediately reduces power on the opposite one to less than take-off power. *S.A.E.*, Preprint for Annual Meeting, January 15 to 19, 1940, 19 pages, 19 illus., 2 tables.

Stress Analysis and Structures

Experiments and Calculation of the Torsion of the Box Structure. E. Cambilargiu. Calculations for the torsion of a box spar of duralumin are carried out by means of the formulas of Bredt and also from the formulas developed by C. Minelli by means of the variational energetic method which takes account of the obstructing dents and other circumstances. The box spar with infinite partitions and the box spar without partitions are calculated. Setup in the test of a wing structure is illustrated.

Results of tests are compared with those obtained by calculation. It is shown that the energetic variational calculation of Minelli has rendered, with several approximations, the effect of flow, effect of obstructing dents, and effect of partitions. The energetic variational theory of Minelli has shown well the phenomenon of the great torsional deformability which occurs when there are no partitions and when the torque is applied by means of two loads with opposite thrusts. Deformations experimentally observed are really smaller than those calculated but that is due to the torsional irrigidity effects owing to strong deformations. *L'Aerotecnica*, October, 1939, pages 975–987, 6 illus., 1 table, many equations.

For One-Sided Attachments. Bulloch screw fitting described is used for attachment to parts, such as the leading edge of an airplane wing, where access can be had from one side only. Rough hole is bored in the face to which an attachment is to be made. Fitting is screwed in with a special tool provided and attachment may be made with ordinary $^{5}/_{16}$ in. screws. When screw is tightened up the nut is drawn toward the face so that the helical spring by which the fitment was inserted, is compressed and whole assembly becomes solid. Spring loading on the screw prevents it from working loose by vibration. Brief note and six drawings illustrating how the fitting is inserted in a plate, access to which is from one side only. *Aeroplane*, January 12, 1940, page 52, 6 illus.

The Nature of Adhesion. N. A. de Bruyne. Facts inconsistent with the author's theory in regard to polar and non-polar adhesion (described in a previous article) are cited by A. R. Weyl. Author's reply is included. *Flight*, January 11, 1940, pages 39–40.

New Research on the Use of Hardening Plastics for Aircraft Construction. W. Kuech. Investigation reported refers mainly to laminated compressed

plastics using phenol resins. Some general research work relating to the influence of the selection of samples, shape of test pieces, and loading speed upon the strength, and the resistance against moisture is explained. Fundamental shear strength tests with laminated compressed plastics are described. Pure phenol resins and laminated materials are compared with thermoplastics based upon methacrylate and polyvinylchloride as to bending strength, impact energy and notching strength. Tests on the behavior of the materials at different temperatures show, for resin-bonded paper and for resin-bonded veneers, a marked relationship between the strength and temperature, caused by internal strains. With thermoplastics, notches result in a smaller influence of the temperature under dynamic loads.

Problem of gluing laminated compressed plastics has been solved. Cold hardening glues based upon aminoplastics give good bonding properties, provided that gluing surfaces are properly treated prior to gluing.

Methods for the development of stringer profiles, spars and shells from laminated plastics are described. These components were tested for strength. For stressed components, resin-bonded veneers seem especially suitable. Manufacture of formed parts from resin-bonded wood veneers by means of pressing in molds can be made considerably easier by use of composite laminated plastics consisting either of veneers and fabric or paper layers. Tests with resin-bonded paper provided with insertions of steel wire mesh gave an increase of 20 to 35 per cent strength. Translated from Jahrbuch 1938 der Deutschen Luftfahrt-Forschung. *Royal Aeronautical Soc. Jour.*, January, 1940, pages 43–73, 26 illus., 9 tables.

The Stabilization of a Thin Sheet by a Continuous Supporting Medium. G. S. Gough, C. F. Elam (Mrs. G. H. Tipper), and N. A. de Bruyne. Theoretical and experimental investigation of the strengths of thin sheets stabilized in various ways by adjacent layers of a material with a value of Young's modulus which is small in relation to that of the thin sheet. Analytic results are expressed in the form of curves which enable a rapid computation to be made of the strength and of the wavelength of the corrugations produced at failure. Where experimental tests have been carried out, a reasonably satisfactory agreement with the theoretical curves has been obtained.

Analyses cover the following eight cases (* denoting cases which were also tested): the semi-infinite supporting medium, with complete adhesion, and with longitudinal freedom between surfaces, respectively; supporting medium of finite thickness with rigid back, with complete adhesion, and * with longitudinal freedom between surfaces, respectively; supporting medium of finite thickness with free back, * with complete adhesion, and with longitudinal freedom, respectively; supporting medium of finite thickness with stressed skin on both faces, * with complete adhesion between surfaces, and with longitudinal freedom, respectively.

Most of the experiments were done with a skin material of spring steel having a tensile strength of from 75 to 100 tons/sq.in. with no measurable elongation, but tests were also made with duralumin, elektron, and birch ply. Supporting medium was expanded ebonite ("Ornazote"), and adhesion between supporting medium and skin was obtained with "Semtex" rubber latex cement. Testing machine, test pieces, experiments and results are described in great detail. *Royal Aeronautical Soc., Jour.*, January, 1940, pages 12–43, 22 illus., 4 tables, many equations.

Steel and Duralumin Beams. L. P. Dudley. Savings in weight to be gained by departing from geometrical similarity when replacing a given steel I-section by a duralumin I-section. It is shown by means of equations that a duralumin beam will be of equal strength to a given steel beam provided that the section modulus of the former is 1.20 times that of the latter, and of equal stiffness to a given steel beam provided that its moment of inertia is three times that of the steel beam. For a steel I-section to be replaced by a duralumin I-section of equal strength and equal stiffness, the latter must have a depth of 2.50 times that of steel.

A duralumin I-section, 1.5 times as deep as a steel I-section of equal strength, will give 1.67 times the deflection, weight of the steel beam being 3.56 times that of the duralumin. A duralumin I-section, 1.5 times as deep as a steel I-section giving the same deflection, will be 1.5 times as strong, weight of steel beam being about 2.1 times that of the duralumin. It is said that little difficulty would be experienced in applying similar treatment in the case of beams of other shape and/or materials. *Aircraft Engg.*, January, 1940, pages 12–14, 3 illus., 1 table, 11 equations.

Aircraft Construction—A Review of Modern Stressed Skin Systems. R. L. Lickley. Main types of construction of wings and fuselages are described with comments on those used in certain military aircraft in service, and the relation between the type of structure and its loads and duties are considered. Description covers: the single-spar wing in general and wings of the Spitfire, Hampden, Flamingo, and Heinkel 112; the box or two-spar wing in general and wings of the Blenheim, Skua, Whitley, Short G class, and Heinkel 111; the multispar wing in general and wings of the Henley, Lockheed and Northrop; the monocoque fuselage in general and fuselages of the Blenheim, Hampden and Whitley; the semi-monocoque fuselage; and standardization of wing and fuselage structures.

No general design of fuselage could be developed, as shape and size of openings, and wing position vary tremendously but if a "code of practice" were developed and used, it should prove very helpful to both R.A.F. maintenance units and airline operators. In multiengine aircraft, outer wings are usually free of equipment and some measure of standardization could be reached. Stressed-skin construction is now sufficiently universal for the various firms of aircraft manufacturers and alloy suppliers to get together and produce a range of standard sections. Suggestions are made for such standard sections. Number of specifications for light alloy sheet and extrusions is unnecessarily large. Three general specifications in each class of material, which should apply, are given. *Flight*, February 8, 1940, pages 114c–114h, 21 illus.

B.S.I. Plywood Specification. Revised B.S. Specification 4 V.3 for plywood for structurally important parts of aircraft issued by the British Standards Institution. Under the provisions relating to the manufacture of the plywood, board 10 in. wide and under must have both faces free from edge joins in veneers. Brief abstract only. *Flight*, February 8, 1940, page 114b.

Effect of the Compression Conditions and the Composition on the Properties of Laminated Compressed Synthetic Resins. W. Kuech. Since little has so far been presented on the properties of laminated synthetic-resin compressed materials, thorough tests were conducted to determine the effect of compression and resin content on the static strength, impact bending, and resistance to humidity of synthetic-resin compressed wood, and compressed materials of cellulose and fabric layers. The tests disclosed that when using suitable resin beams, proper selection of resin proportion, and special production methods, the mechanical properties of synthetic-resin compressed materials suitable for aircraft construction, or general machine construction, can be increased.

Test procedures are described and test results are discussed in detail, including effect of the compression pressure and resin content in the case of laminated layers containing phenol resins (compressed wood, cellulose material layers, and fabric layers), and tests on the improvement of compressed materials in regard to ureaformaldehyde resins and polyvinyl chlorides as binding agents, to extension of resin sections, and to combined resin sections.

Data given in tables include: relation between the tensile strength of resin sections and tensile strength of manufactured compressed materials; properties of laminated compressed materials with various resins as binding agents; properties of compressed materials with fabric layers, in the case of age hardening, under tension (resin content 34 per cent, loading speed 100 kg./cm.²-min.); properties of compressed materials with various resin sections, including cellulose-layer compressed material, HTZ (a special material with wood veneer, cellulose and fabric layers), and compressed resin. Report of the D.V.L. Institute for Materials Research. *V.D.I.*, December 30, 1939, pages 1309–1316, 16 illus., 5 tables.

Structural Design. J. D. North. Evolution of airplane structures and possible future trends are discussed by the designer of the Boulton-Paul Defiant. "Important changes in the wing structure described appear to me likely to arise only from external causes. Permissible reduction of span²/W with or without increased wing loading, would follow reduction of importance of induced drag (*e.g.*, increased power for climb) with or without increase in stalling speed or higher maximum lift devices. This increase in loading may be accompanied by the necessity for greater strength. For example, raising wing loading to 80 lb./sq.ft. and load factors to 15 on 'one-piece' wings without apertures might bring the self-stabilized shell in sight. Perhaps the ingenious Vickers' wing foreshadows the coalescence of its geodesics into a continuum. Further important changes in wing economy may follow a more perfect distribution of mass, with consequent reduction of shears and bending moments. A great increase in scale at one and the same time makes possible, and is made possible by, such arrangement."

Fuselage design is also considered. Some effects of material on that part of the structure which carries stresses arising from air loads are discussed. *Flight*, February 8, 1940, pages 114i-114j, 115, 116, 6 illus.

Then and Now. W. O. Manning. Aircraft construction of 1916 is described and the advantages of wood construction for production are pointed out. *Flight*, February 8, 1940, pages 114a-114b, 1 illus.

Aircraft Accessories

General Solution of the "Skewed Axis" Landing Gear. O. F. Oldendorph. Geometric requirements of cantilever-type landing gears which retract laterally are outlined to minimize design difficulties, and a graphical method is presented which affords a direct solution. An analytical method is included by means of which the angle of inclination of the retraction axis may be computed to any desired degree of accuracy. *Aero Digest*, February, 1940, pages 101–102, 105, 4 illus.

Problems of Ancillary Services for Aircraft. R. H. Chaplin and F. Nixon. First issue—Last half of Royal Aeronautical Society paper previously abstracted from preprint.

Second issue—First part of discussion of Royal Aeronautical Society paper. Illustrations include: Gnôme Rhône accessory gearbox; Marconi-Stanley unit embodying a 98 cc. two-stroke motor weighing 34 lb. and used primarily for battery charging and driving the radio generator; the A.B.C. auxiliary power unit for flying boats; and Air Equipment's compressed-air drive. A list of hydraulic pumps, purpose and characteristics is given.

Third issue—Concluding part of discussion. Illustrations include drawings of the Garelli Avio Model R.B. air compressor with generator, and Rotax three-cylinder aircooled radial auxiliary engine developing 16.8 hp. and used to drive a 10-kw. alternator. *Aeroplane*, January 26, February 2 and 9, 1940, pages 112–115, 142–144, and 181–184, 18 illus., 1 table.

Undercarriages. B. Foster. Review of present types of alighting gear and how they were developed, question of whether tailwheels will disappear, the trend back to hydraulic operation, advantages of the nosewheel, and design in the future are considered. Alighting-gear designs of British Landing Gears, Ltd., MacLaren, Dowty, "Levered Suspension," Lockheed (undercarriages not aircraft), especially the "Airdraulic," are described. Comments are given on the alighting gear of the following aircraft, in some cases accompanied by illustrations: Douglas DB-7 bomber, Cygnet, Hawker Hurricane, Armstrong-Whitworth Whitley and Ensign, DeHavilland Flamingo and Albatross, Supermarine Spitfire, Lockheed Lodestar, Curtiss-Wright substratosphere transport, Westland Lysander, Hawker Henley, Bristol Beaufort and Bombay, Gloster Gladiator, and Martin Baker fighter.

Skis, flying-boat hulls, and seaplane floats are also taken up, and reference is made to the floats of the large Blohm and Voss Ha.140, single float of the Curtiss Scout observation seaplane, and planing bottom of the Saro Lerwick, the two latter being illustrated. *Flight*, February 8, 1940, pages 129–132, 12 illus.

Advantages and Inconveniences of Various Types of Alighting Gear. P. E. Mercier. Mechanical properties of alighting gear and its stability in the landing run are discussed. Stability and restoring of the steerable wheel; stability in landing run of the complete equipment; rotation without and with displacement; stability in braking; stability in crabbing; maneuverability and defense; the directed wheel; and properties of the complete undercarriage assembly for the conventional and tricycle types. From "La Science Aérienne et L'Aérotechnique" No. 5, 1939. *Rivista Aeronautica*, December, 1939, pages 465–473, 3 illus., equations.

Non-Magnetic Materials for Aircraft. R. Hadekel. Metals available for such parts as controls and nose wheels which require the use of non-magnetic materials, are briefly reviewed, including: stainless steels of the 18/8 per cent chromium-nickel group; other austenitic steels; nickel alloys; copper alloys, especially aluminum bronzes and beryllium bronze; and non-magnetic substitutes for spring steels as alternatives to phosphor bronze. *Aircraft Engg.*, January, 1940, page 15.

TESTING EQUIPMENT

Cathode-Ray Undercarriage Testing. New type of undercarriage recording apparatus installed by Aircraft Components, Ltd., for recording results obtained with static tests on undercarriage units. Recorder consists of three large cathode-ray oscillograph tubes with amplifiers and a special camera to record the oscillograph spot movement on a photographic strip 6-in. wide. Accelerometer is of the variable-gap condenser type which effectively measures acceleration force on a suspended mass. Condenser element is in the form of a capsule with a steel diaphragm contained in the base of the accelerometer. Acceleration forces from − 10G to + 20G can be measured. Description of device with illustrations and typical record. *Aircraft Engg.*, January, 1940, page 17, 3 illus.

Aircraft Manufacture

Interchangeability in Modern Aircraft Production. C. J. Hertel. Society of Automotive Engineers paper presented at the National Aircraft Production Meeting. See page 129, January, 1940, issue of Journal for abstract of preprint. *Aircraft Engg.*, January, 1940, pages 21–23, 2 illus.

Tools for the Workshop. Avery strut-testing machines Henry Pels large-capacity guillotine shears; new type of spot welder recently developed by Metropolitan Vickers Electrical Company for welding aluminum and its alloys with special reference to duralumin and other heat-treatable alloys; and Henry Pels combined plate-splitting shears with punch, bar angle and T-bevel cropper and notcher. Descriptions of these machines. A preceding article describes the Cincinnati universal dividing head for which a wide-range attachment is available. *Aircraft Engg.*, January, 1940, pages 28–29 and 27, 29, 9 illus.

Welding Technique in Aircraft Construction. K. Queitsch. Continuation of translation of the German Air Force welding handbook, "Schweisstecknik im Flugzeugbau." Practical information on the welding of steel tubes, including: shrinking tests on a continuous tube having welded cross joints and on a tubular longeron with several struts at a node point; shrinkages occurring in welded tubular trusses; and comparison of the three tubular truss types with regard to their suitability for welding. Drawings illustrate results of welding shrinkage tests on various types of trusses, as well as longerons with T-struts, with three struts, and with a multiple joint, and a diagram of buckling of the three trusses. Continued. *Aircraft Engg.*, January, 1940, pages 24–26, 17 illus., 2 tables.

Delaying Age-Hardening Alloys. Refrigerated rivet cabinet developed by the British Pressed Steel Company for rapid cooling of light-alloy blanks after heat treatment. A low-temperature quench tank is located inside the cabinet itself and the refrigerator is placed alongside the salt-bath shop, so that the blanks can be cooled and stored immediately after heat treatment. The Prestcold quench system cools the material rapidly. Company uses light insulated and refrigerated trucks in its factory to carry large batches of blanks from the main cold room to flatteners and presses. Short note on advantages obtained from this system which is the result of company research. *Aeroplane*, February 2, 1940, page 156, 1 illus.

A Plan for Aircraft Expansion. P. N. Jansen, Curtiss Aeroplane Division. Short abstract of National Aircraft Production Meeting paper. See page 129 January, 1940, issue of the Journal for abstract of preprint. *S.A.E. Jour. (Trans.)*, February, 1940, page 92.

The German Aeronautical Industry. H. J. A. Wilson. Development, organization of factories, production figures, products developed and manufactured, and aircraft and aircraft-engine companies of the German aeronautical industry are discussed in great detail. Difficulty at present is whether sufficiently large quantities of airplanes, engines and equipment necessary for conduct of the war can be produced. It took more than six and a half years to achieve a monthly production of about 1000 machines. To treble this output, which is demanded by the German Air Ministry, seems a very difficult task.

Each of the five designing companies has one main works reserved for the design, building, testing and developing of new types. Strictly separated from these a number of mass-production works exist. Most of the component parts are manufactured by subcontracting firms. Types of aircraft are not brilliant achievements but are good average products, being only developments of machines known for years. Solution of the engine problem has been very difficult. One of the reasons for abandonment by the German Air Force of the construction of four-engined bombers two years ago was the small capacity of the engine works. Another intricate problem still not completely solved, is that of raw materials.

Comments are also given on German aircraft. Even if the average service version of the Me.109 single-seater fighter is slower than the Me.113R record machine and shows deficiencies, such as insufficient maneuverability—its landing speed is over 100 m.p.h.—it is still a dangerous weapon in the hands of a skilled pilot. Me.109s for the protection of Berlin are equipped with cannon and machine guns, and range does not seem to be large as they carry fuel for only one hour. Long article. *Aircraft Engg.*, January, 1940, pages, 3–7, 9, 8 illus., 2 tables.

Aircraft

Tail Treatments. Comparative photographs of the tail design of some British and German airplanes, including the Gloster Gladiator, Hawker Hurricane, Supermarine Spitfire, Messerschmitt Me.109, Blackburn Skua, Boulton-Paul Defiant, Bristol Blenheim, Fairey Battle, Airspeed Oxford, Avro Anson, Vickers-Armstrong Wellington, Heinkel He.111K Mk.VA (Series H), Handley-Page Hampden, Dornier Do.17, DeHavilland Flamingo, Armstrong-Whitworth Whitley, Bristol Bombay, and Lockheed Hudsons. *Aeroplane*, January 5, 1940, page 14, 18 illus.

France

Tests of the Bloch 161 Designed for Air France. Weighing 10,300 kg. empty the four-engine Bloch 161 transports normally a movable load of 6700 kg., of which 1820 kg. is fuel, raising its flying weight to 17 tons, but this weight can be raised to 21 tons. With a normal load of 152 kg./per square meter and 4.600 kg./hp. the Bloch 161 has a practical ceiling of 8000 meters. In still air, its range would be 1200 km. and with authorized overload with full tanks 2300 km. Short description. *Les Ailes*, December 14, 1939, page 5.

Germany

Arado Ar.96B Monoplane. The Ar.96B is a development of the Ar.96A trainer and is designed for training in piloting and observation, and for instruction in acrobatic flight, blind and night flying, firing machine guns, bombardment, photography, and telegraphy. It can also be used as a light combat airplane, given its armament and characteristics. Argus As.410A engine developing from 360 to 450 hp. Wing span 11 meters. Wing loading 102 kg./square meter. Power loading 4.86 kg./hp. Maximum speed 340 km./hr. at 3000 meters. Long description, characteristics, performance. From "Flugsport" No. 23, 1939. *Rivista Aeronautica*, December, 1939, pages 461–463, 3 illus., 1 table.

The Blohm and Voss Ha-137. A. Frachet. The Ha.137 airplane is similar to the Ju.87, and is likewise designed as a dive bomber. Equipped as a single seater, it has not a very high load capacity. Wings from the front view have the form of a W. First of the Ha.137s were powered by Junkers Jumo 210 650-hp. engines but later ones are powered with engines developing around 1000 hp. Armament consists of two machine guns fixed in the engine cowling and firing through the propellers; two other machine guns or two 20-mm. cannons installed either in the wings or in the landing gear. Wing span 11.15 meters; total weight 2400 kg. Maximum speed (with 650-hp. engine) 340 km./hr. Range 600 km. Description of construction, armament, characteristics and performance. *Les Ailes*, December 21, 1939, page 3, 3 illus.

Heinkel 115 Seaplane for Torpedo Dropping. A. Frachet. It is possible that the He.115 three-seater twin-engine float seaplane is used in mine laying. Its normal load is 800 kg., but with reduced range, it could carry more. In 1939 an He.115 attempted the distance record, taking off from Bodden on the Baltic with a supply of fuel to permit it to be flown 10,000 km. without landing, but came down in the South Atlantic after having covered 7000 km. It can also be equipped as a land plane. The He.115 seaplane carries either a 800-kg. torpedo in the lower part of the fuselage or a bomb-dropping apparatus carrying the same load of bombs. Two B.M.W. 132.N engines each developing 865 hp. for take-off. Wing span 22.15 meters. Total load 9100 kg. Maximum speed 355 km./hr. at 3500 meters. Climb to 2000 meters 8 min. 5 sec., and to 4000 meters 18 min. Range 2100 km. at 295 km./hr. and, without bombs, 3000 km. Description of construction, armament and characteristics, as well as performances announced by the Germans. *Les Ailes*, December 14, 1939, page 3, 3 illus.

The Heinkel Dissected. Heinkel He.111K Mk. VA Series H long-range bomber (two 1200-hp. Junkers Jumo 211A gasoline-injection engines with two-speed superchargers), which is described in great detail, was shot down near Edinburgh on October 28. Outstanding points of interest are the gasoline-injection system of the engines and the "bullet-proof" fuel tanks.

Whole of the external skin is flush-riveted and all plates are carefully lapped and toggled so there are no raised edges. Wing has been extensively modified and given a straight taper, presumably for ease of production. Tips have been redesigned and ailerons now have both servo tabs and trimming tabs, but the plain camber-changing flaps remain unaltered.

There is no metal in the fuel tanks except for the flanged pipe connection. Inner container of the tank is made in the manner of a fiber suitcase of about $^1/_{16}$-in. fiber, and is enclosed in an overcoat of grey buckskin $^1/_8$ in. thick. Outside is a $^1/_8$-in. layer of natural raw rubber which swells up on contact with gasoline from a bullet hole.

For landing pilot can raise himself with seats and controls to see through a sliding hatch in the roof. Bomb cell is behind the pilot's position in center section of the fuselage. Main undercarriage wheels retract backwards and are completely housed in aft fairings of the engine nacelles behind doors. Radius rods behind the oleo legs take bending loads, relieving the oleo legs of these loads. Maximum claimed speed of 274 m.p.h. at 13,100 ft. seems fairly reasonable. This is 9 m.p.h. faster than the Wellington bomber which has more wetted area. Wellington is said to be a much better airplane with greater range, defense and bomb load achieved on less power.

Long detailed description of design, construction, armament, fuel tanks, and gasoline-injection engines. Photographs and drawings of the undercarriage are included. *Aeroplane*, January 5, 1940, pages 18–21, 12 illus.

Henschel 124 Multi-Purpose Airplane. A. Frachet. Henschel 124 twin-engine three-seater multipurpose airplane is similar to the Messerschmitt Me.110. Its manufacturers have attributed very high performances to it, notably a range of 4000 km. at an average speed of 350 km./hr. Nose of the fuselage is removable and interchangeable with others more suitable for the mission for which the airplane is being equipped. Different types of nose for each mission are briefly described. For ground attack in low flight, the front bay of the fuselage is provided with a transparent carriage serving as a support for the semi-fixed guns which are operated by the pilot, firing along the axis of the airplane, and consisting of either four machine guns or two machine guns and two cannons. Two B.M.W. 132Dc engines each developing 870 hp. at 3000 meters. Maximum speed 435 km./hr. Climb to 6000 meters in 17 min. 5 sec. Wing span 18.20 meters. Weight in flight 7230 kg. Useful movable load around 3 tons. Description of construction, armament, characteristics and performances. *Les Ailes*, December 28, 1939, page 3, 2 illus.

The Messerschmitt Me.109. Single spar of the main plane of the Me.109 is situated at the unusual position of 45 per cent of the chord from the leading edge. This curious design is occasioned by the room required for housing the undercarriage forward of the spar and leads to the barrels of the machine guns protruding considerably. Wing is thin and there is a fair-sized bulge caused by the cartridge chute under each gun.

Sole load-carrying attachments of the main plane are fittings on the top and bottom flanges of the spar (vertical base of about 10 or 12 in.) and a front fitting bolted to the undercarriage-leg pintle casting (horizontal base of less than 2 ft.). Automatic slots and plain flaps are commendable. Use of hat-section stringers riveted to the fuselage skin by the "crown" is novel and cannot make for excessive strength. Few details, dimensions, weights loadings, and performance and three-view general-arrangement drawing are given. Maximum speed with D.B.601 engine 354 m.p.h. at 12,300 ft. *Aircraft Engg.*, January, 1940, page 14, 1 illus., 1 table.

The Messerschmitt Me.110 Two-Motor Fighter. Wings, engines, nacelles, fuselage and tail are described in great detail, performance is calculated, and dimensions and the estimated weights, loadings and performance are given in a table. Photographs, polars and range curves, and cutaway drawing are included. Uses of the Me.110 in action in Poland, on the Western Front as escorts for the Do.17, and in attacks on Wellington bombers are described. Twelve Wellingtons were intercepted by Messerschmitts and three Wellingtons, four Me.109s and one Me.110 were shot down. Twelve Me.110s attacked three Wellingtons and two Wellingtons and four Messerschmitts were shot down.

Span 55 ft. Estimated gross loaded weight 14,800 lb. Estimated wing loading 35.80 lb./sq. ft. Estimated maximum speed 365 m.p.h. at 16,500 ft. Cruising range at 15,000 ft., 820 miles at 365 m.p.h., 1500 miles at 215 m.p.h., 1750 miles at 175 m.p.h. Map shows disposition of plants of the Messerschmitt A.G. around the airport at Augsburg, Bavaria. *Aeroplane*, January 12, 1940, pages 36–41, 9 illus., 1 table. See also *Flight*, January 18, 1940, pages 54a–54b, 4 illus.

Dive Bombers in Poland. Work of the Junkers Ju.87 airplanes in the Polish campaign. Preferred targets were concrete forts, airports, level crossings and bridges behind the lines, railway stations, and staff headquarters.

A second note comments on the use of direct-injection Mercedes-Benz engines in Messerschmitt fighters in Poland. A reduction in weight (around 180 g./hp. instead of 230 g./hp.), in comparison with carburetor engines, is obtained. Messerschmitts took off immediately on alarm with engines still cold, great speed of take-off being a tribute to properties of fuel injection. For taking off with a cold engine, they have supplementary tanks controlled by the pilot. On starting, pump delivers a mixture of etaer and gasoline, this, with a good spark, giving a sure and immediate start. Pilot then changes fuel to a mixture of gasoline and oil, for immediate take-off. As soon as an engine reaches its running temperature and oil is circulating normally, he changes over to ordinary gasoline. *Flight*, February 15, 1940, page 163.

Germany's Latest. H. F. King. Startling designs for the Luftwaffe. There are in service a German reconnaissance machine, the Focke-Wulf Fw.189, apparently based on an Avia type, which was in turn inspired by the Fokker G.I, and a Focke-Wulf Fw.198 single-engine single-seater pusher fighter, similar not so much to the Fokker D.23 as to the French Hanriot H.110 built in 1932–33.

Improved version of the Blohm and Voss Ha.140 twin-engine floatplane (believed to have been built to same specifications as the Heinkel He.115) has large leading-edge slats.

Improved Junkers J.86K has a cleaned up nose and gun mounting appears to resemble the Heinkel He.111 though smaller. Two B.M.W.132 medium supercharged engines. Top speed at 8530 ft. 233 m.p.h. Range 885 miles. Ceiling 23,300 ft. Gross weight 18,100 lb. Racks for total bomb load of 2750 lb. Few details of performance. Photographs of all these aircraft are given.

A short note following the article deals with the gun sight fitted on the Me.109 which uses an electric current. *Flight*, February 15, 1940, pages 144–148, 11 illus.

GREAT BRITAIN

Box Kite to Beaufort. C. M. Poulsen. History of the Bristol company which has completed 30 years of unbroken activity. Thirty-six airplanes and 12 engines developed by the company, the former during the period from 1910 to 1940, are illustrated with a few comments. *Flight*, February 15, 1940, pages 149, 150a–150d, 151–152, 50 illus.

Miles Mastery. Development in design from the Miles Kestrel Trainer of 1937 to the Miles Master Advanced Trainer (715-hp. Rolls-Royce Kestrel XXX engine) of 1939, now in full production for the R.A.F., is described. *Aeroplane*, February 2, 1940, pages 136–137, 4 illus.

The Trail of the Comet. Design of the De Havilland Comet for the MacRobertson Race to Australia, and that of the four-engine Albatross transport, which owed much to the success of the Comet, are described. *Aeroplane*, January 25, 1940, pages 110–111, 4 illus.

Aeronautics in 1939. Use of aircraft in the war, and some new British aircraft. Bristol Beaufort (two 1000-hp. Bristol Taurus engines, and controllable cooling system) is a combined bomber, reconnaissance, torpedo-carrying and general-purpose four-seater landplane claimed to be the world's fastest bomber. Hawker Hotspur low-wing two-seater fighter (Rolls-Royce Merlin II engine developing 1030 hp. at 16,250 ft., De Havilland two-pitch metal propeller), resembles the Hurricane and has practically the same dimensions.

The Defiant low-wing two-seater fighter (Rolls-Royce Merlin engine driving a three-bladed De Havilland controllable-pitch propeller) carries a power-operated gun turret amidships. Roc Fleet Air Arm two-seater fighter (Bristol Perseus XII engine) has interchangeable float and wheel undercarriage. Few details of construction and design, and dimensions are given for these airplanes. *Engineering*, January 5, 1940, pages 5–6, 7 illus. on supplementary plates.

From "Britain First" to Blenheim IV. Development of the Bristol Blenheim bomber from the Bristol 142 "Britain First" transport of 1935 down to the new long-nosed Mark IV version. *Aeroplane*, January 19, 1940, pages 74–75, 4 illus.

The Latest Taylorcraft. New version of the British-built Taylorcraft two-seater high-wing monoplane (90-hp. Cirrus Minor engine) has a cruising speed of 102 m.p.h. and range (normal) of 250 miles and (maximum) of 375 miles. Few details, characteristics, performance. *Aeroplane*, January 5, 1940, pages 22, 27, 2 illus.

A New Trainer. Marendaz Trainer two-seater tandem low-wing trainer (90-hp. Cirrus Minor engine) is the latest machine to be equipped with built-in slit-slots as a standard feature. As a primary trainer the machine is built without flaps and brakes but these can be fitted for more advanced work. Maximum speed 124 m.p.h. Range (normal) 350 miles, and with extra tanks 700 miles. Short description, characteristics, performance. *Aeroplane*, January 5, 1940, pages 22–23, 2 illus.

ITALY

The Romeo 43 and 44 Seaplanes of the Italian Air Force. The Romeo Ro-43 of the Italian Navy is a catapultable two-seater biplane having a single central float and folding wings. It is designed for missions of pursuit and reconnaissance and has two synchronized Breda machine guns firing through the propeller disk, and a flexible gun operated by the observer. Piaggio engine developing 700 hp. at 1000 meters. Wing span 11.58 meters. Flying weight 2400 kg. Maximum speed 316 km./hr. at 2000 meters. Climb to 5000 meters 1 min. 37 sec. Few details and drawing.

The Ro.44 is a single-seater interceptor, speed of climb of which is a little faster because the installations for the observer are eliminated. Range is 480 km. Brief reference only to the Ro.44. *Les Ailes*, January 18, 1940, page 5, 1 illus.

U.S.A.

The Controllability of the Curtiss. An American Curtiss Hawk H.75A single-seater fighter (915-hp. Pratt and Whitney Wasp engine), of the type supplied to the Armée de l'Air, is now at the Royal Aircraft Establishment for test.

"There it has earned the unanimous admiration of all who have flown it, because of the brilliance of its controls. . ." *Aeroplane*, January 26, 1940, page 115.

Curtiss Advanced Combat Trainer Passes Final Tests. Curtiss Falcon 22 all-metal two-seater advanced combat trainer constructed for a foreign government is notably speedy and maneuverable, as demonstrated during recent flight tests. Designed for training fighting pilots, it is smaller than the Curtiss Hawk 75A pursuit. It is adapted to all types of training including gunnery, bombing, and instrument flying, and in case of emergency would serve as a first-class auxiliary defense plane. Wright Whirlwind engine rated at 420-hp. at 1400 ft. and using 80 octane fuel. Maximum speed 215 m.p.h. Climb to 4920 ft. in 2.9 min. Service ceiling 25,900 ft. Cruising range 518 miles. Short description of construction. *U.S. Air Services*, February, 1940, pages 20–21, 1 illus.

North American Primary Trainer. NA-35 open-type tandem-seater low-wing primary trainer (Menasco Pirate C4S-2 four-cylinder inverted inline supercharged engine developing 165 hp. for take-off) has a maximum speed of 140 m.p.h. Flaps are of slotted trailing-edge type and extend inboard from aluminum-alloy differentially-controlled ailerons. Wing span 29 ft. 8.87 in. Rate of climb 900 ft./min. Service ceiling 18,500 ft. Cruising range 305 miles. Description, characteristics, performance. *Aero Digest*, February, 1940, pages 113–114, 5 illus., 1 table.

Introducing—North American NA-35 two-seater low-wing military and commercial primary trainer. Rearwin Model 8135 Cloudster three-seater. Two Fairchild "24" airplanes (Standard and DeLuxe). Ryan STM-2 low-wing military trainer (125-hp. Menasco C-4 or 150-hp. supercharged C-4S engine), similar to the Air Corps' new PT-20. Stinson Model 105 sports airplane (80-hp. Continental engine). Descriptions. *Western Flying*, February, 1940, pages 23–24, 30, 32, 34, 8 illus.

Stinson Model 105 for 1940. Stinson Model 105 (80-hp. Continental engine) is a refined version of the three-place high-wing monoplane and has improved fairing of flaps, ailerons and elevator slots, and improved rudder action, which reduces effort and synchronizes with other controls. Take-off with full load has been reduced 18 per cent, or 150 ft. Rate of climb has been increased 12 per cent and service ceiling 20 per cent. Ground handling in high winds has been improved by increasing the size of hydraulic brakes and by use of a steerable tail wheel. Cruising speed 111 m.p.h. at 4800 ft. Cruising range 425 miles. Description and characteristics. *Aero Digest*, February, 1940, page 114, 2 illus., 1 table.

Vultee—An Industry Portrait. S. Calkins. Development of the Vultee Aircraft Company, various aircraft produced, especially military aircraft, and the company's recent expansion are described. *Western Flying*, February, 1940, pages 14–17, 26, 10 illus.

Aircraft Procurement. Commander L. B. Richardson. Navy Department's present procurement procedure is discussed, covering: type specifications; design data requested; expediting trials; selection of experimental aircraft: straight and alternate bids; choice of engines; propeller procurement; comparison of costs and prices of aircraft and engines compiled by the Bureau of Supplies and Accounts; coordination with the Air Corps.; inspection of aircraft, engines and other equipment under construction and manufacture as a vital part of procurement; and Army and Navy inspection on a joint basis. *Aero Digest*, February, 1940, pages 48, 85–86, 163.

"Big Boats." Commander A. M. Pride. Development of large flying boats for the U.S. Navy; grouping of flying-boat squadrons in wings; navigation problem; landing and take-off technique; internal and external communications required; and future trends. *Aero Digest*, February, 1940, pages 41–43, 164, 8 illus.

Air Transportation

Post-War Civil Flying. G. Scott. Civil flying in 1939, and wartime operation of air transport are discussed. Separation of the transport of mails from passenger transport is considered, and the maintenance of a skeleton organization on paper is suggested for Britain during the war. *Aeroplane*, January 19, 1940, page 91.

The Trend of Air Transportation. Edmund T. Allen. Technical developments in aircraft, and improvements in airline operation which have made possible the present commercial success attained are discussed, including: recent air-transport developments; technical advance of transport airplanes; safety features of modern airplanes; means of lightening the pilot's burden; development of cruising control; demands for air-transport service; determination of economical use of aircraft; developments in aircraft engines; provisions for comfort of passengers; automatic controls to promote safety; and aircraft maintenance problems. *Inst. Mechanical Engrs., Jour. & Proc.*, December, 1939, pages 127–140, 14 illus.

Propellers

Airscrews. In Britain greater interest has been shown in methods of blade manufacture than in design of pitch-changing mechanisms. A few details are given of the Jablo (Heine) system employing laminated wood and resin, the system of Hordern-Richmond Aircraft, Ltd., which uses the B.T.H. process giving a synthetic-resin-impregnated fabric covering, and work of the DeHavilland and Airscrew companies. Mention is made of the Hamilton Hydromatic, Curtiss electric full-feathering, Rotol, and Fairey Contra propellers, the last consisting of two three-bladed fully-feathering constant-speed propellers revolving in opposite directions.

Illustrations include: photographs of a Junkers propeller on a Jumo 211 engine indicating that it can be completely feathered in flight; drawing of the installation of the Alfa Romeo reversible-pitch propeller, one of the main uses of which is to permit execution of 360° turns by a flying boat on the water; the Curtiss four-bladed v.p. propeller; Fairey "Contra" counter-rotating propeller combination; Everel single-bladed propeller; and large and small Hydromatic propellers. *Flight*, February 8, 1940, pages 125–126, 7 illus.

Miscellaneous

Sharp Technical Debates Mark 35th Annual Meeting. Account of Annual Meeting of the Society with abstracts of the papers presented and discussions taking place. *S.A.E. Jour.*, February, 1940, pages 15–20, 35–51, 64, many illus.

Aircraft Instruments

The Echo Altimeter. F. Chichester. Instrument and method discussed were used to chart, in a short time, a large area of sea bottom to an accuracy of 3 in., and were described in Lt. Commdr. D. MacMillan's book "Precision Echo Sounding." Possibilities of applying sonic methods to the measurement of altitude of an airplane are considered. An American radio altimeter is mentioned and an application of the marine echo sounder developed in England is described. Limitations of the radio altimeter are pointed out. *Flight*, January 11, 1940, pages 31–32, 3 illus.

Stall Warning. C.M.W. stall indicator tested in Australia is described, and the question of whether a light or a hooter is the best warning is discussed. *Flight*, February 1, 1940, page 105. Photograph and brief reference. *Aeroplane*, January 5, 1940, page 22, 1 illus.

Electrical Equipment

Electric Power for Aircraft. W. J. Clardy. The past 18 months has been a period of intense development of auxiliary engines, generators, motors, and control for airplanes. The two systems now available, 110-volt 400-cycle 3-phase alternating current and the 24-volt direct current, meet present requirements and provide for future increases in the use of electric power. The 24-volt d.c. system appears to be best for standardizing on one potential for a number of different sized airplanes. The 110-volt 400-cycle 3-phase a.c. system is applicable to large aircraft. Both systems are described. *Aero Digest*, February, 1940, pages 105, 156.

Voltage Regulation in Aircraft Generators. Requirements of an aircraft generator, and alterations and additions which have to be made to ordinary machines to meet the needs of constant voltage are described. Characteristics of shunt and compound-wound generators are dealt with, especially their behavior under varying loads and speeds. To be continued. *Aeroplane*, February 2, 1940, pages 148–149, 4 illus.

Fuel and Oil Tanks

Elektron Tanks. Design and construction of magnesium-alloy tanks for fuel and oil are described in great detail. Ten rules to be followed in the design of these tanks are presented, since their design should not be based on practice common to aluminum, aluminum alloys, steel or brass. Welding procedure in the case of a tank incorporating baffles attached to a T-section, design and procedure for other welded parts and especially profile tanks

are discussed. Economy in weight achieved in the case of sumps or filler casings by using a welded-up structure of sheet, castings and machined parts, and the greater gauge thickness which can be used with Elektron, resulting in the reduction of number of baffles necessary for stiffness, are pointed out. An example of the resistance of Elektron to vibration in actual use is given in an account of tests made on an Elektron tank manufactured by Essex Aero, Ltd. *Flight*, February 8, 1940, pages 133–136, 16 illus.

The Revival of the Self-Sealing Tank. Development of fuel tanks since 1918 is reviewed, and mention is made of the latest German tanks. Design of the Henderson safety tank is described and results of tests made with it are discussed. Henderson tanks are crashproof and bullet-proof. Each tank is virtually three tanks in one. Hencorite seal between the inner and outer shell is vulcanized to both. Tanks weigh about 1.25 lb./gal. Bullet holes can be repaired in about 12 min. and repair can be done anywhere, often without removing the tank. The filling is noncorrodible and is insoluble in gasoline. Baffles and internal fittings are secured to the walls of the tank by a patent self-releasing method.

Photographs on another page show the tank made by the Fireproof Tanks, Ltd. for the Bristol Blenheim. *Aeroplane*, February 2, 1940, pages 141 and 156, 4 illus.

A New Fire- and Crash-Proof Tank. A 95-gal. duralumin tank produced by Fireproof Tanks, Ltd., which was three-quarters full of aviation gasoline, and suitably covered with C.I.M.A. protection, was perforated from a range of 6¾ yd. with ordinary 0.303 bullets and 0.440 Desirgue incendiary bullets, the latter from a machine gun. Tank stood single shots and bursts of fire of both types of bullets alternately, and on three different sides up to a total of 42 rounds, and still remained gasoline tight. A 70-gal. tank three-quarters full was dropped from a height of 60 ft. into a gasoline fire on the ground below, which had been made by setting alight to earth soaked with about 25 gal. of gasoline. Although the fire burnt for 4 min. around the tank, the protection prevented the tank's contents from catching fire. Few details of tank. *Flight*, January 4, 1940, page 19.

Miscellaneous Equipment

Compressed Air Line Service. In the Schrader quick-acting coupler, the deflection valve is held against the resisting washer by air or water pressure until the valve is depressed by the insertion of the adapter. Brief note and drawings. *Aeroplane*, January 12, 1940, page 60, 2 illus.

Seeing Your Way Clear. Electric Screenclear demister and defroster approved by the British Air Ministry for aircraft. Few details. *Flight*, January 11, 1940, page 41, 1 illus.

International Radiogoniometric Cartography. Lt. Col. A. A. R. Grasso. Radiogoniometric charts of India, Irak, Ireland, Jugoslavia, Lettonia, Mexico, Norway, Low Countries, Poland, Siam, and the United States are discussed with some photographs. Continued. *Rivista Aeronautica*, December, 1939, pages 420–432, 5 illus.

Ear Defenders. For any ordinary sound of high or low pitch, the Mallock-Armstrong ear defender merely acts as a relay and passes on, without any diminution, the vibrations to the human ear drum. If sound or pressure waves exceed a certain intensity, the diaphragm reaches the limit of its movement between the bronze gauzes and only a subdued noise is transmitted. A bakelite molding fits in the ear and carries at the outer end a goldbeaters skin diaphragm, vibrations of which are limited by pieces of very fine bronze gauze on either side. Few details and drawing. *Flight*, February 8, 1940, page 141, 1 illus.

An Improved Pneumatic Boat. Pidcock semirigid pneumatic boat is described which has water ballast to make the boat more seaworthy. *Aeroplane*, February 2, 1940, page 149, 3 illus.

"Visual" Link Trainers for the R.A.F. By use of the new "Visual Link" trainer which was devised by a squadron leader at one of the R.A.F. elementary flying schools, all-the-year-round elementary flying instruction becomes possible. Dummy fuselage is set up in a large circular room which has a cyclorama of various views reproduced on the walls including sunshine, clouds, mist, seascape, and large towns. Fuselage is moved by powerful bellows and is steered on its turntable through all the motions of actual flying. Indicators have been placed under the wings, nose, and tail so that the instructor can tell how much bank, etc., the pupil is applying. Some of the new Links have upper mainplanes, and others have a device linked with the throttle which gives an action similar to flaps. Brief note. *Aeroplane*, February 2, 1940, page 139.

Description of new "Visual" Link trainers, now being used to give primary pilotage training to the British Volunteer Reserve pilots, and of method of training. *Flight*, February 1, 1940, pages 100–101, 4 illus.

New Equipment. Triumph non-deteriorating electric light battery. New Cuno oil filters for use in aircraft hydraulic systems and engines. Koehler G-2A fuel cock with Neoprene seal. Aeronautical Trading engine-timing instrument. Pyle-National completely sealed runway marker light. Watson-Stillman overhung gap-type hydraulic flanging press. Aviation Wax No. 20 for aluminum surfaces. Colalloy atomic welding paste and Colaweld atomic welding materials. Chesterman height gage, 40-in. model. Firestone-Westinghouse stationary non-reflecting light for seaplane bases. Nine new types of Elastic Stop Nut Corporation nuts. Brief descriptions or, in some cases, few details. *Aero Digest*, February, 1940, pages 155–156, 4 illus.

Parachutes

Shock-Absorbing Parachute. To reduce shock of opening, if the wearer has just left a very fast military airplane, a new parachute, the Salvator D.39, has been developed in Italy. Shock absorber is a hole at the center with an elastic rim which allows the hole to dilate and spill the air until some reduction of speed has occurred. Total weight is said to be about 71 lb. Brief reference only. *Flight*, February 15, 1940, page 153.

Materials

New Developments in Automotive Materials. New pre-finished bonded metals, Nickel Aluminum and Chrome Aluminum, introduced by American Nickeloid Company. Dura-Bond method of bonding soft rubber and Neoprene to steel and aluminum, announced by Hewitt Rubber Corporation. Lincoln Stainweld D stainless-steel electrode for welding stainless steel of the 25 per cent chromium 20 per cent nickel type. Magalloy frame jig used by Buick. Torflex flexible bushing developed by the Harris Products Company. Brief descriptions. *Automotive Industries*, February 15, 1940, pages 150–151, 2 illus.

More Lightness. Airscrew Company's new material consists of a multi-ply sandwich of expanded rubber or Ozonote, spruce stringers and plywood with a metal casing which, in addition to providing a considerable portion of the strength, serves as an armor against damage by knocks. Moisture absorption as well as lightness and strength of the material is another property. Material is said to be excellent for sound and vibration proofing. Few details. *Flight*, January 11, 1940, page 42, 1 illus.

Metals

The Influence of Various Lubricants on the Seizure of Hard Steel and Bronze. D. Clayton. Significant differences having been found with a series of typical lubricants in seizure tests in the four-ball apparatus, the work has been extended to cover a wider range of substances and also a change of rubbing material. Report refers briefly to typical previous results and describes apparatus used in the present investigation, the behavior of a cutting oil and its emulsion, and related tests with water and no lubricant, using hard steel balls. Results are given for bronze balls, and for combinations of bronze and steel balls, using first ordinary lubricants of several types and then, in the case of bronze and steel together, the thin liquids, gasoline and water.

Fundamentally, purpose of this work which has been carried out in the Engineering Department of the National Physical Laboratory is to provide information on the nature of wear and seizure, but present results are of immediate interest as well as a contribution to the wider issue, being relevant to metal cutting, worm and worm-wheel behavior, and rubbing of metals in the presence of water, gasoline, etc. Test results given reveal various aspects of the phenomenon of metallic cohesion. Long article. *Engineering*, February 9, 1940, pages 131–135, 144, 29 illus.

Powder Metallurgy in War and Peace. Short survey of some recent applications of powder metallurgy, including: possibility of producing alloys of precise composition which, because of melting difficulties due to oxidation and other effects, are impossible to produce by more orthodox methods; use as welding-rod coatings; forming of electrode core from powders; anodes in X-ray tubes; and special physical properties obtainable only by powder treatment. *Metal Industry*, February 9, 1940, pages 147–148.

Metallurgists Report Year's Developments. Metal powders—effect of time, temperature and pressure on density; surface quality—rolled steel surface dependent upon mold-wall surface; stainless steels—effect of pretreating temperature on creep and on elastic properties; and non-ferrous metals—recrystallization, anodic films, cold work and annealing. Review of papers on these subjects which were given at the meeting of the American Institute of Mining and Metallurgical Engineers. *Iron Age*, February 22, 1940, pages 36–43, 2 illus.

Corrosion and Protective Coatings

Protecting Steel against Corrosion. J. C. Hudson. Findings of the Protective Coatings Subcommittee of the British Corrosion Committee, and reasons for the findings. All material should be thoroughly descaled prior to application of first priming coat of paint. Descaling should be carried out by sand or shot blasting or by some kindred process, or alternatively by pickling. Exposure to weathering for however long a period, followed by hand cleaning is not recommended, except in special cases. If pickling is adopted, the duplex method, including a finishing dip in dilute phosphoric acid is probably best. Descaling process should take place as late in the fabricating process as practicable, due precaution should be taken to keep the material reasonably free from rust prior to descaling, and application of priming coat of paint should follow immediately after descaling and under good conditions. Midland Metallurgical Society paper. *Iron Age*, February 15, 1940, pages 28–31, 1 illus.

Electroplating on Aluminum. A. Bergman. Methods of treating aluminum surfaces to obtain an adherent deposit, and types of plating solutions, particularly Travers process. *Iron Age*, February 8, 1940, pages 40–42, 3 illus.

Iron and Steel

"18 and 8" and Related Stainless Steels. W. M. Mitchell. Good and bad metallurgical characteristics of the "18 and 8" steels are discussed. Those factors affecting design, whether for corrosion resistance or engineering properties, are explained, and information on the use of modified compositions for special purposes is presented. To be continued. *Metals & Alloys*, January, 1940, pages 14–18, 4 illus., 3 tables.

Communications on the Deformation and Fracture of Mild Steel under Cyclic Stresses. H. J. Gough and W. A. Wood. Long written discussions on paper published in a previous issue (Volume 141, page 175), discussion being presented by A. H. Jay, H. Moeller, E. Orowan, L. W. Schuster. The authors' replies are included. *Inst. Mechanical Engrs., Jour. & Proc.*, January, 1940, pages 175–183, 2 illus.

The Fatigue Endurance of Killed, Capped and Rimmed Steels. J. F. McDowell. Killed, capped and rimmed steels of about the same composition and nearly identical physical properties vary quite definitely in their ability to withstand repeated stress reversals, according to results of the tests described. In the calculation of limiting stresses, cognizance of this fact should be given when either a capped or rimmed steel is involved. Skin decarburization is shown to influence fatigue endurance of a low carbon steel (0.21 percent carbon). This skin effect is unquestionably responsible for the inability of rimmed or capped steels to withstand repeated stress reversals on a plane with the normal carbon-skin killed steel.

Types of steels used in the test, Krouse flat sheet fatigue machine designed to test sheet and plate under repeated bending stresses, results of fatigue tests, and causes of variation in fatigue endurance of various steels are described. *Metals & Alloys*, January, 1940, pages 27–32, 10 illus., 8 tables.

Silver in Stainless Steel. New type of silver stainless steel has been developed primarily to resist pit corrosion but, in addition to this attribute, it is said to present other striking characteristics, such as free machinability, low work hardening, increased heat conductivity, and an ability to take a high polish. The steel was developed as a result of a research program sponsored by the Chemical Foundation and carried out by a group of scientists at M.I.T. Development of the new steel, composition and physical properties of silver stainless steel as castings, and as forgings, and the technique involved are described. *Metals & Alloys*, January, 1940, pages 18–19, 1 table.

Copper Steels. C. T. Greenidge and C. H. Lorig. Three-year atmospheric-corrosion tests on 43 steels were conducted at Battelle Memorial Institute to determine the effect of copper on the corrosion resistance of plain and low-alloy steels. Corrosion resistance of low-carbon and low-alloy steels was markedly improved by addition of 0.20 to 0.50 percent copper. While higher copper contents increased the resistance still further, improvement was small. Copper was effective in increasing corrosion resistance of silicon-chromium-phosphorus steels, in which as well as in plain low-carbon steels, 0.20 to 0.50 percent copper appeared to double the life of the steel. Chromium and phosphorus were likewise effective in reducing rate of corrosion of the copper-silicon steels. Small amounts of tin, aluminum, nickel, or silicon in copper-bearing low-carbon steel had little effect on corrosion

resistance. Method of testing and results. *Iron Age*, February 15, 1940, pages 21–25, 6 illus., 2 tables.

Gears of Iron Powder Save Material—Cut Manufacturing Costs—and Are Held within Close Tolerances. Durex Iron, possessing a tensile strength of 20,000 to 25,000 lb./sq.in., is used by Moraine Products Division of General Motors Corporation for oil engine pump gears. Iron powder is pressed into finely polished precision steel molds, then sintered at 2000°F. Perfectly formed involute profiles are made without undercut at root and base circle. Dimensional tolerances of the finished gear are exceptionally close and finish machining is not required. *Automotive Industries*, February 15, 1940, pages 158–159, 4 illus.

METAL WORKING

Superfinish. D. A. Wallace. Superfinishing technique, developed by Chrysler Corporation, is said to refine a surface to the closest approach to a geometrically true and unworked crystalline surface that has ever been commercially produced. Ways in which Superfinishing accomplishes this method for measuring the resulting surfaces, metallurgy of the surface finish, and the lubrication of bearing surfaces are discussed in great detail. *S.A.E. Jour. (Trans.)*, February, 1940, pages 69–92, 50 illus.

NONFERROUS ALLOYS

Anodic Treatment of Aluminum. H. A. Smith. Alumilite treatment of aluminum is described, including equipment, racks, rinsing, color work, and sealing. Electrolyte is sulfuric acid requiring a much lower voltage than commonly used. Credit for much of the early investigations on anodic treatment of aluminum is given to H. Sutton of the Royal Aircraft Establishment. In Japan both chromic acid and oxalic acid treatments are used. In Germany mixtures of chromic and oxalic acid are in common use, requiring quite high voltage. Paper presented before the Buffalo Branch, American Electroplaters Society. *Metal Industry*, January 26, 1940, pages 113–115, 1 table.

The Heat Treatment of "K" Monel and "Z" Nickel. Box hardening; semi-bright hardening; protection from contamination by foreign material; hardening processes; soft annealing; and stress relieving. *Heat Treating & Forging*, January, 1940, pages 16–20, 25, 3 illus., 2 tables.

TESTING OF METALS

Radiographic Development in the Casting Industries. C. W. Briggs. Use of radiography for testing in the foundry. Early history and the development of radiography; proper radiographic interpretation; radiography as a help to designers of castings; radiography as an aid in establishing the manufacturing procedure of a casting; and use of radiography for aluminum and steel castings. *Metals & Alloys*, January, 1940, pages 1–5, 4 illus.

Surface Profiles in Microinches. By means of the Brush surface analyzer described, topographic charts of surfaces of finished parts are provided and readings less than 1 microinch, absolute, can be made. Device consists of a surface analyzer head mounted on an adjustable stand, a calibrating amplifier and a direct-inking oscillograph. Piezoelectric or Bimorph crystals are used both in the analyzing head and to actuate the pen. Description. *Iron Age*, February 15, 1940, pages 32–33, 3 illus.

WELDING

Design of Welded Rigid Frames. M. P. Korn. Bases for welded rigid frames; ties between bases; location of neutral axis; welded versus riveted joints; functioning of knees in rigid frames; behavior characteristics of tension resistance area, and of compression resistance area; and design of knees in welded rigid frames. *Welding Jour.*, January, 1940, pages 30–35, 9 illus.

Measurement of Grooved Welded Connections in the Case of Alternating Bending Stress. A. Thum and A. Erker. By means of fatigue tests on welded T-joints, the fatigue strength of connecting welds and the most suitable dimensions of these welds were determined in order to obtain a high degree of durability of the entire connection. Tests and testing machine are described and results are discussed. On the basis of the tests, methods are given for calculating welded connections which are continuously stressed. *V.D.I.*, December 23, 1939, pages 1293–1297, 14 illus., 4 tables.

A New Process for the Welding of Thin Sheets. A new method of welding thin sheets has been developed by two Swiss mechanics, A. S. and H. Weibel, and has proved satisfactory in practice because of its simplicity and good results. Heat necessary for melting of the material is obtained by electric current. Although two carbon electrodes are used it is not an application of arc welding and neither is it resistance welding in the conventional sense. Heat is developed in the tips of the carbon electrodes which are at a given angle to each other and which at the contact side with the angle are beveled to a strictly prescribed extent. Welding speed is up to 0.5 meter per min. Only defect is the wearing of the electrode tips which require frequent attention. *A.T.Z.*, December 25, 1939, pages 657–658, 2 illus.

Strength of Welds in Aluminum-Manganese Alloy Plate. G. O. Hoglund. Results of tests are presented to provide such specific information as is now available to supply a partial basis for code regulations on unfired pressure vessels. *Welding Jour., Welding Res. Sup.*, January, 1940, pages 12s–13s, 3 illus.

Paint

Corrosion-Resistant Paint. Sigal aluminum-silicon compound developed in Germany consists of the eutectic alloy of aluminum (87 percent) and silicon (13 percent) with elementary silicon added. After it has been ground to a fine powder (no residue on 16,000 meshes/sq.in.) it is mixed with a combination of linseed oil and a resinous material. Priming coats are made up without oil and have greater elasticity. Brief reference only. *Flight*, February 15, 1940, page 153.

Paint Protection of Metals against Corrosion. H. A. Nelson. Recent developments in the paint industry are reviewed including: supplementing linseed oil; phosphate and chromate-pretreatments and conditioning of the metal surface; adhesion of primers and their protection against the beginning and spreading of corrosion under the paint system; importance of polarity of the main binding constituent; baking or stoving; inhibiting pigments; and basic pigments. Discussion of the paper is included. Electrochemical Society paper. *Paint, Oil & Chemical Rev.*, February 15, 1940, pages 9–10, 24–27.

Plastics

Service-Temperature Flow Characteristics of Thermoplastics. W. F. Bartoe. Effects of external and internal stresses. Results of tests. *Mechanical Engg.*, December, 1939, pages 892–894, 10 illus.

Casein Plastics. G. H. Brother. Some of the problems are presented, the solution of which awaits the fundamental investigation of casein itself and of casein complexes such as casein-formaldehyde. Manufacture of casein plastic materials, buttons from plastics, technical improvements in manufacturing process, and thermosetting compounds are discussed. *Industrial & Engg. Chemistry, Ind. Ed.*, January, 1940, pages 31–33, 1 illus.

Meteorology

Modern Meteorology as a Service of Aeronautics. G. Severi. The operations of a modern meteorological organization for assistance to flight are summarized. Two "systems of war" for the forecasting of weather are described, and the activities of the meteorologist for aero-radiometric assistance along the large airways and for the meteorological studies of stratospheric flight are discussed. *Rivista Aeronautica*, December, 1939, pages 402–419, 4 illus., 7 equations.

Comment on Refsdal's "Aerogram" and the "Tephigram." A. F. Spilhaus. Refsdal has proposed a diagram for aerological work with coordinates of T log p and log T which preserve the area-energy relationship of a true thermodynamic diagram. Convenience of this ingenious device for geodynamic height computation has caused the diagram to be adopted in certain quarters. The author points out that an exactly similar procedure may be carried out on Sir Napier Shaw's Tephigram. *Am. Meteorological Soc., Bul.*, January, 1940, pages 1–3, 3 illus., equations.

Recent Developments in the British Columbia Meteorological Division. W. A. Thorn. Outstanding contributions to the development of meteorology in Canada during the past year were made, as in other services, almost entirely to meet the pressing demands of aviation. Number of stations telegraphing reports several times daily in British Columbia increased from six to 23, including eight radio stations along the coast. Collection of Pacific and Rocky Mountain data is also mentioned. *Am. Meteorological Soc., Bul.*, January, 1940, pages 10–12.

Reminiscences on "A.P.O.B." Flights and Fliers. A. M. Marks, Jr. Airplane weather observations in continental United States. Account of some of the problems encountered by pilots on their flights, and description of instruments developed. *Am. Meteorological Soc., Bul.*, January, 1940, pages 18–22.

Bearings

Studies in Lubrication—Electrolytic Models of Full Journal Bearings. F. Morgan, M. Muskat, and D. W. Reed. An electrolytic model of a full journal bearing having a ratio of journal displacement to radial clearance of 0.1 has been constructed. Reliability of the model was established by comparing the results observed for the infinitely wide bearings with those predicted by the theory of Reynolds. Results obtained for models of journal bearings of finite width, bearings with circumferential grooves, and bearings with sources of lubricant are also in agreement with hydrodynamic theory. Apparatus, test procedure, and results are described. *Jour. Applied Physics*, February, 1940, pages 141–152, 14 illus., 22 equations.

Flexible Bearings. Harris controlled bearings are rubber bushings compounded and cured by new methods and "controlled" by the clamping of the endplates squeezing the bushing both radially and axially to a predetermined extent. It is claimed that a range of movement can be as much as 70° each way from the normal position before creep occurs. Torflex couplings are for direct drives up to $1^1/_4$ in. diameter shafts, each shaft being gripped by a rubber bush enclosed in a threaded steel cap. Few details. *Flight*, January 11, 1940, page 41, 2 illus.

Fuels and Lubricants

Availability and Characteristics of Aviation Safety Fuels. R. E. Ellis and W. J. Sweeney, Standard Oil Development Co. There are two possibilities for safety fuel of high octane number. The aromatic type is immediately available from selected crudes through the application of proven methods of solvent extraction. Supplies of material of this type can also be augmented by hydrocarbon conversion processes such as thermal and catalytic reforming, dehydrogenation, destructive hydrogenation, catalytic cracking, and vapor phase cracking. Paraffinic type of suitable octane number for aviation use is not available in any present known crude oils. Therefore paraffinic safety fuels will of necessity be 100 per cent synthetic products, comparable to blending agents now used in aviation gasoline (isooctane, hydrocodimer, alkylate and neohexane).

Both aromatic and paraffinic safety fuels are discussed and compared. Octane number characteristics of the 300°–400°F. virgin distillates from various crudes, and estimated concentration of aromatics in the 300°–400°F. fraction from various crudes are shown in tables. Graphs illustrate: approximate correlation of the closed cup flash point of petroleum distillates with initial and final boiling points; effect of boiling range of cut on availability of aromatics of 100°F. flash point; calorific values of safety fuels and of ordinary fuels; and lower heating values. *S.A.E. Preprint for Annual Meeting*, January 15 to 19, 1940, 12 pages, 5 illus., 2 tables.

Characteristics of Diesel Fuels Influencing Power and Economy. A. J. Blackwood and G. H. Cloud, Standard Oil Development Co. Data obtained on an extended fuel research program and very largely concerning power and fuel economy which are obtained when using fuels differing in their physical and chemical characteristics. Effects of fuel volatility, ignition quality, and fuel viscosity are discussed in detail. Assuming complete combustion, fuel volatility effects the pints per brake horsepower hour only indirectly as it is related to heating value and ignition quality. Most present-day engines have fixed injection timing, and on such engines ignition quality is a major factor in determining volumetric fuel economy in the upper speed ranges. At the lower engine speeds, heating value in terms of b.t.u. per gallon, or as estimated from A.P.I. Gravity, is the most important consideration. *S.A.E. Jour. (Trans.)*, February, 1940, pages 49–53, 6 illus., 2 tables.

The Improvement in Octane Number and Lead Susceptibility. D. L. Yabroff and A. C. Nixon, Shell Development Co. Solutizer process accomplishes the sweetening of gasoline by extracting the mercaptans completely, by the use of a solutized caustic solution (one of high solvency power). Data are presented indicating that an improvement results in octane number and lead susceptibility, as compared with sour gasoline. Data include: properties of untreated gasolines; effect of solutizer sweetening on octane number and lead susceptibility; comparison of TEL requirements of sour and solutizer-sweetened gasolines; average octane numbers for 31 different gasolines, for 17 cracked gasolines, and for 8 straightrun gasolines, showing improvements; average tetraethyl lead saving as a function of the per cent mercaptan sulfur in sour gasoline, and as cents per barrel as a function of lead required to raise the octane number of the sour gasoline 5 units. *Oil & Gas Jour.*, February 22, 1940, pages 74–76, 4 illus., 4 tables.

Engine Design and Research

Air-Intake Efficiency. S. Riess. Results of preliminary investigations undertaken in Poland (just before the outbreak of war) into the effects of air-intake shape on power at altitude. Critical altitude of a supercharged engine is shown to depend on the value of the dynamic pressure at the place of the carburetor intake created by the aircraft velocity, and may be increased by fitting a suitably shaped efficient air intake.

At top speed at critical altitudes results often fall below expectations and some method should be evolved for checking carburetor air-intake efficiency. In full-throttle level flights at altitudes near the critical one data should be taken by recording instruments on flight altitude, aircraft speed, absolute intake manifold pressure, engine r.p.m., total pressure at the carburetor air intake, dynamic pressure at the place of the air intake, and air temperature at the carburetor intake. Procedure may be used for checking blower compression ratio and the validity of empirical formulas evolved for correction of that ratio with change of air-intake temperature. An airspeed recorder, wind-tunnel-calibrated in millimeters of water head, should be used for determination of dynamic pressure at the carburetor intake. *Aircraft Engg.*, January, 1940, page 16, 3 equations.

Engine Combustion and Pressure Development. G. M. Rassweiler, L. Withrow and W. Cornelius. Effects of mixture ratio, spark position and throttle opening on flame pictures and pressure cards. High-speed motion pictures of flames in a gasoline engine, and pressure records of the same explosions are examined to determine effects of changing these three factors. Some quantitative relationships between fraction of charge burned and pressure developed at any time during the explosion have been tested with the experimental data observed while operating the engine under several sets of conditions. It is shown that, by means of these relationships, both the fractional volume and fractional mass of charge inflamed at any time may be calculated from the pressure cards with an accuracy comparable with the accuracy of the present experimental observations. *S.A.E. Jour.* (*Trans.*), January, 1940, pages 25–48, 23 illus., 8 tables.

Output-Increase in C. I. Engines. G. S. Kammer. Methods of obtaining improved performance from the two-stroke sleeve-valve type of compression-ignition engine. Best way seemed to be to adapt the speed characteristics of the sleeve to some kind of periodically varying cycle and to increase the sleeve speed during discharge and charge period and consequently obtain greater port height, faster port area increase and decrease and, if possible, to reach a figure sufficient to shrink the period required for these operations to those corresponding to the four-stroke's pre-opening of exhaust and post-closing of inlet ports. An eccentric mechanism for periodically varying the speed of a sleeve valve, and timing of a specially designed engine are described and illustrated. Example of the exhaust and scavenge port openings obtained with the engine is illustrated and discussed.

Really great advantage lies in the possibility of exhaust turbo charging which, suitably arranged in connection with the new sleeve drive, can be advantageously used up to very high altitudes. Since port area is ample and timing can be altered as required, it becomes possible to divide the exhaust into two parts at will, namely one leading to the turbine and the other into atmosphere, giving a solution of the turbo charging problem. Increase in scavenge pressure need not affect the efficiency of the turbine as temperatures before the turbine are broadly controllable. *Aircraft Engg.*, January, 1940, pages 10–11, 20, 3 illus.

Rocket Efficiency. First issue—Further comment on the articles on exhaust efflux propulsion by F. W. Lanchester. An equation thought to have a more rational basis for calculating instantaneous propulsive efficiency of a rocket is derived by A. V. Cleaver. Dr. Lanchester's reply, and criticism by R. W. Corbitt are included.

Second issue—Criticism of the previous articles is given by D. Ramsay. Efficiencies greater than 100 per cent are said to be impossible and another line of approach is presented by the analogy of a machine gun mounted on a moving platform. The author's reply is included. *Flight*, January 4 and 11, 1940, pages 14 and 40.

Rocket Efficiency. F. W. Lanchester. Further discussion of the articles "Efflux Propulsion," including: neglect of kinetic energy in the calculations, pointed out by C. L. Johnson, A. V. Cleaver, and H. J. Thomson; a contribution from Sweden (F. H. Turner); and a long reply by the author with drawings. *Flight*, February 1, 1940, pages 96h, 97, 98, 3 illus.

The Aircraft Engine and the War. L. S. Hobbs. General conclusions regarding quantity, performance, and types of engines to be expected as a result of the war. Predictions made include: fabrication of engines in hitherto unthought of quantities; large power increases secured only by addition of more cylinders which will be strung out lengthwise; increases of the order of 50 to 70 per cent in power output; no rapid changes from types of engines employed at present; continuation of the air- versus liquid-cooling competition; use of gear-driven superchargers with multiple stages and intercooling, and of exhaust-turbine driven superchargers if present difficulties are overcome; adoption of extension shafts, reverse rotation, propeller change-speed gears, dual propeller rotation and other unorthodox ideas required by aircraft designers only if they are of the simplest and most straightforward design; reduction of 15 per cent in fuel consumption; and adoption of safety fuels although now offering real but not insurmountable problems.

This country has an excellent chance of maintaining a reasonable position in the race if the vital importance of research is recognized and necessary action taken quickly. It will be some time before engines in excess of 3000 hp. will be produced in large numbers. *U.S. Air Services*, February, 1940, page 36.

Aircraft Power Plants. Considerations affecting design and construction of aircraft engines, and modern trends. The Pratt and Whitney Double Wasp 14-cylinder radial with extension shaft is considered to give a "cowled radial installation comparable in efficiency with contemporary liquid-cooled practice." Photographs of this engine and a drawing of the Hispano-Suiza H 24-cylinder engine with extension shaft are given. Vee-type engine will probably be retained for powers of 1500-2000 hp. The Fiat AS-6 racing engine consisting of two 12-cylinder vee-type units placed back to back with a gear box between them, has two concentric propellers, one for each engine, driven through offset gearing and concentric shafts. A French bomber has been designed to utilize two sets of Hispano Suiza Series Y engines joined in similar fashion.

Discussion also covers: the air- versus liquid-cooling and the gasoline-injection carburetor controversies; aircraft Diesel development; cylinder design; sleeve valve engines; superchargers; and crankshafts.

The B.M.W.-Lanova 114 V-4 radial Diesel engine (compression ratio 14.8:1) with glycol radiators between cylinders is illustrated and referred to. Other photographs include: the Potez flat engine of which little has lately been heard; installation of a Perseus sleeve-valve radial in a Canadian Westland Lysander; rear end of a Rolls-Royce Merlin with sectioned supercharger; dismantled injection pump of the Jumo 211A engine; cowlings of the Curtiss P-42, Bell Airacuda, and Boulton-Paul Defiant; Jumo 205; components of the cylinder of the Perseus sleeve-valve engine; Wright Duplex Cyclone; and frontal views (more or less to scale for comparison) of the Rolls-Royce Merlin, Allison XB-3420, Daimler-Benz D.B.,600, Napier Dagger, and Bristol Taurus engines. *Flight*, February 8, 1940, pages 117–122, 18 illus.

Damping in the Case of Cast Iron with Special Consideration to Cast Crankshafts. J. Geiger. For the determination of damping in the case of resonance, in place of the cast-swinging test, a method is preferred which operates also in resonance with excitation by a harmonic force. This applies especially for different types of cast iron. Damping is considerably higher in the case of an unused bar than after repeated loading and unloading and gradually approaches a constant final value which is reached after approximately 200,000 reversals of stress. Damping of the different types of cast iron is high in general when the cast iron is inferior in quality with reference to its strength, that is the lower its shearing modulus of elasticity.

Damping of the different casting types, based on type, is from 80 to 15 per cent higher than in the case of crankshaft steels. Because of the assistance of other essential dampings, in order to reduce considerably the critical torsional stresses by means of higher material damping, it is necessary to make the entire shafting of cast iron and to provide for it, outside the crankshaft, a longer shaft piece highly stressed in torque.

Test apparatus is described and illustrated in drawings and photographs, and test procedure and results are discussed. *A.T.Z.*, December 25, 1939, pages 634–644, 15 illus., 1 table, equations.

Fundamental Mechanical Aspects of Boundary Lubrication. H. Blok, Royal Dutch Shell. Rational classification of various types of boundary lubrication can be drawn up on the basis of mechanical conditions in region of contact between rubbing surfaces. It may be expected that the physico-chemical results may be fitted in well. Nature of contact is considered separately for concentrated and for dispersed contact. Local contact pressures and their distribution in the region of contact are described which, besides being dependent on the load, are chiefly dependent on the geometrical features of the rubbing surfaces and on their elastic and plastic properties. Local temperatures and their distribution in the region of contact are discussed which are dependent on local pressures, on dimensions of surfaces of actual contact, on coefficient of kinetic friction, on movements of rubbing surfaces relative to the surfaces of actual contact, and on thermal properties of the rubbing surfaces. The following effects of motion, with the exception of tangential vibrations, are considered for concentrated and disbursed contacts: oil wedge formation, frictional stresses, temperature flashes and thermal stresses, effects of impact loading, and duty-recovery cycle. Mild, high-temperature, high-pressure and extreme boundary lubrication are considered in detail. Appendix gives a survey of experimental data on frictional vibrations under conditions of boundary lubrications, importance and occurrence of frictional vibrations, and theory of frictional relaxation vibrations. *S.A.E. Jour.* (*Trans.*), February, 1940, pages 54–68, 10 illus., 17 equations.

Piston-Ring Grooves. E. Mickel. For the same durability, it is possible to reduce the space required on piston-ring grooves to half the size by means of the "unloaded" groove radius in place of the rounded groove base. This is important since, in the case of the simple rounded corner, the piston ring will wear. Either the piston ring must be cut obliquely at the inner edges or it is weakened radially; or the groove must be made deeper radially, whereby again a larger as well as a more highly-stressed fillet is produced. As expected the simple sharp edge at higher stresses has proved unsatisfactory. Also a form adopted in a foreign country, perhaps because of its simple method of production, did not provide the expected improvements.

The disadvantages of the circular form of corner of the hollow groove are pointed out, and the distribution of stress is illustrated. An "unloaded" groove radius is proposed and a diagram of the distribution of stress is given. A simple method for production of the piston ring groove with "unloaded" radius is suggested. *Luftwissen*, December, 1939, pages 305–308, 11 illus.

The Running-In of Piston Rings and Their Improvement by Methods of Surface Treatment. C. Englische. Theory of running in, excessive oil consumption, necessity for surface treatment, loosening method, surface treatment by means of structural changes of material, and metallic and non-metallic coatings on the bearing surfaces are discussed with microphotographs of the surfaces produced.

Proper surface treatment of piston rings gives two results. Smooth perfect bearing surfaces are developed rapidly and without difficulty, and in addition, in a much shorter time than in the case of the untreated ring, the final compression ratio is obtained which can be expected from a satisfactorily operating piston ring. *A.T.Z.*, December 25, 1939, pages 648–652, 13 illus.

Power Plants for Aircraft. H. E. Hartney. Progress in aircraft engines in the past 25 years is briefly reviewed, the modern Allison "C 1710-C 6" is compared with the Liberty engine, and directions in which engine progress will take place in the next 20 years are predicted. *Western Flying*, February, 1940, pages 20–22, 28.

Torsional Durability of Case Hardened Hollow Crankpins with Internal Reinforced Oil Holes. H. Cornelius and F. Bollenrath. Results of further tests made at the D.V.L. Institute for Materials Research. Chemical composition of the new test pieces deviates somewhat from that of the former. Carbon, chromium and molybdenum contents of the steel were reduced, and the nickel content increased. Test results, especially torsional strength and structure of the case-hardened layer and core are discussed. Report demonstrates that values previously given for durability coefficients of case-hardened pieces should not be regarded as characteristic, as pointed out in the previous report. *V.D.I.* December 2, 1939, pages 1257–1258, 2 illus., 1 table.

The Trend towards the Large Aircraft Engine. F. Jaklitsch. A 2000-hp. Diesel engine having four crankshafts arranged at the corners of a square is said to have been proposed by Junkers and is listed in the table of high-powered aircraft engines as a 1938 development. In place of previous systems of a single-sleeve type, a double-sleeve design is used in the form of the conventional opposed-piston design in which as structural elements the tested Jumo 205 is used. Power is transmitted by four gears on the four crankshafts to a central gear located on the propeller shaft. Drawings of this engine, and a few details only (no data) are given at the end of a very long discussion of the trends of design of large aircraft engines with references to types in use and under development.

Power requirements of large aircraft in general and of the aircraft of the various countries are discussed. One table shows the flying weight, passengers and engines used, for very large aircraft (five landplanes and four flying boats in operation or under flight test, and eighteen projected), the largest being the 180-ton Consolidated A.C.

A second table gives characteristics (in most cases) and performance for 101 very large aircraft engines developed in various countries in the period 1918–1939, 21 having been developed in 1938 and 16 in 1939. The largest engines are the 2400-hp. Allison 24X of 1925, 2300-hp. Rolls-Royce R 12 V of 1931, 3100-hp. Fiat AS.6 24 V of 1934, 2500-hp. Rolls-Royce Blue Bird 12 V of 1935, 2000-hp. Hispano-Suiza 82 24 H of 1938, 2000-hp. Junkers

Diesel of 1938 with four moving crankshafts, 2250-hp. Rodgers two-row radial two-cycle Diesel of 1938, 2000-hp. Allison double 12 V of 1939, 2000-hp. Wright Duplex Cyclone two-row radial of 1939, and Hispano-Suiza 90 24 H of 1939.

Past developments (1918–1939) in large aircraft engines are reviewed in regard to form, design, bore, stroke and horsepower. Expressions are derived for engine coefficients. Cooling, cylinder number and performance are taken up in detail. Engines with a small number of cylinders and those with a large number of cylinders are discussed. *A.T.Z.*, November 25, 1939, pages 583–594, 18 illus., 3 tables, 16 equations.

Wear of Diesel-Engine Cylinders and Rings. P. S. Lane. Wear is considered from the viewpoint of cylinder and ring materials, rather than from design or operating angle. Discussion includes: rates of wear; laboratory wear testing; Diesel-engine cylinder castings; variation in structure at port areas; nature of liner structures; nature of piston-ring irons; suggested structural characteristics of metals for cylinders; composite and bimetallic construction; rubbing-surface finishes; chemical surface treatments; and ring efficiency. *A.S.M.E. Trans.*, February, 1940, pages 95–110, 21 illus., 10 tables.

Engine Manufacture

Air Conditioning for Aircraft Engines. Interesting tooling setup for precision work and adoption of new type fluorescent lighting on a very large scale are two features of the new Indianapolis plant of the Allison Division of General Motors Corporation, "where aircraft engines for the U.S. Army will be produced in larger quantities than heretofore practicable." Description of plant which is air conditioned, and equipment. *Iron Age*, February 15, 1940, pages 26–27, 4 illus.

Balance Becomes Electric. Alternating voltages created in the magnetic pickups of a balancing machine by crankshaft vibration are converted to drill depths on an automatic machine. Semi-automatic balancing machine is described, which was recently installed by International Harvester. Installation consists of a Gisholt Dynetric unbalance measuring machine electrically connected to a Leland-Gifford automatic drilling machine which is semiautomatic and is arranged to correct for unbalance by drilling four holes in the cheeks, two from each end. *Am. Machinist*, February 21, 1940, page 87, 1 illus.

Design Problems in the Quantity Production of Aircraft Engines. H. C. Hill. Paper presented at the National Aircraft Production meeting. See page 133, January, 1940, issue of the Journal for abstract of preprint. *S.A.E. Jour.* (*Trans.*) January, 1940, pages 18–24, 8 illus., 1 table.

Modern Machines and Methods of Manufacturing Aircraft Engines. G. Carro-Cao. Study of machines and operations for the production of radial aircraft engines in small series, which was made in the Piaggio plant at Pontedera, is described. Modern tendencies in the construction of machine tools are pointed out with references to the "Power Pack" of the Ingersoll Milling Machine Company, Sundstrand Rigidmil, and Bullard Mult-au-Matic. Conditions to be fulfilled by machine tools for work on small series are indicated. Some characteristic cases of operation are illustrated and some special machines designed and constructed for some typical operations are described. Arrangements of heads of special boring machines for operations on the lightening holes of the engine framework, on attachments for cylinders, sleeves of exhaust-gas passages and spark-plug holes are illustrated in drawings and discussed. *L'Aerotecnica*, October, 1939, pages 945–974, 45 illus.

Engine Testing

Double Test Stands for Aircraft Engines. C. Weltin. In test runs of airplane engines on the torque stand, generally the drive is first obtained by electric motor and then by power from engine being tested. In the case of the double test stands developed by the author, considerable saving is possible as compared with conventional test run methods.

In a U-formed wind tunnel two torque stands of conventional design are so arranged that the test engines face each other with their propeller ends approximately 1.5 meters apart. For carrying out continuously alternating drives, the torque stands are supplied with symmetrical equipment and are provided with conventional measuring instruments which can be supervised from a common control desk.

Drawing shows the tunnel and arrangement of equipment including: the engine operating under its own power; the wind-driven engine; brake-pressure propeller for the brakes of the first engine; wind blades by which the second engine is operated; cooler; regulating valve for the cooler; conduits for the cooling agent; shunt lines; condenser; ventilation conduits; and guide vanes for the tunnel. *V.D.I.*, November 25, 1939, pages 1237–1238, 3 illus.

Thermocouples for Measurement of Gas Temperature in Internal Combustion Engines. H. H. Berg. The thermocouple and the spark-plug thermocouple, which were developed by the D.V.L., are illustrated in cross-sectional drawings and are described. The former is used for measurements of temperatures up to approximately 1000°, and principally of gas temperatures in engines. The D.V.L. spark-plug thermocouple can be installed in almost any spark plug without greatly affecting its heating value. Test arrangement of the cold junction in melting ice is also illustrated. *V.D.I.*, December 2, 1939, pages 1259–1260, 3 illus.

Engines

The Daimler Benz D.B.601. Several propeller reduction gear ratios are employed on the D.B.601. The D.B.601Aa is geared 1:1.55, and the D.B601Ba 1:1.88. A shell gun can be fitted. Engine is basically similar to the D.B.600 but is improved in a number of ways including a hydraulic supercharger drive with automatic and continuous variation of blower speed and a hydraulic coupling located on the shaft of the supercharger impeller and into which oil is fed by a metering pump. Metering pump consists of two identical gear pumps. One continually feeds engine oil into the coupling, while oil flow of other is regulated by sleeve valve controlled by barometric cells, so that with increasing altitude a progressively greater portion of oil is added to the flow acting on the coupling. At an altitude of 13,000 ft., highest supercharger drive ratio (about 10:1) is attained giving a supercharger speed of about 25,000 r.p.m.

Volume of engine 2080 cu.in. Rated power 1000 hp. at 2500 r.p.m. Take-off power 1175 hp. Two-speed supercharger. Dry weight 1268 lb. Short description of improvements. *Flight*, February 15, 1940, page 148, 1 illus.

An Excellent Score. Twelve engines developed by the Bristol company during the last 20 years are illustrated with brief comments on each. *Flight*, February 15, 1930, pages 151–152, 6 illus.

A New Aero-Motor Firm. Three new sleeve-valve medium-power aircraft engines have been designed by D.R.P. Engines, Ltd., but work has been held up on account of the War. The Velox eight-cylinder geared and supercharged inverted-vee aircooled left-hand tractor engine develops 240 hp. at 3600 r.p.m. It is said that cost of complete overhaul would be less than that for a normal engine of equivalent power. The Velox is described and reference is made to the 100-hp. four-cylinder Metcar, and the 600-hp. 16-cylinder Excelsior engines. *Aeroplane*, January 26, 1940, page 115, 1 illus.

Hispano-Suiza 12Y-39 Engine. Twelve-cylinder 60° vee liquid-cooled engine develops 810 hp. on the ground and 910 hp. at 3400 meters. It is equipped with centrifugal supercharger and turbine having two speeds. Bore 150 mm. Stroke 170 mm. Cylinder capacity 36 liters. Weight empty without generator 480 kg. Width 0.764 meters. Height 0.945 meters. Fuel consumption 265 gr./hp-hr. Oil consumption 8 gr./hp-hr. Description, characteristics, performance. From "L'Air" No. 476. *Rivista Aeronautica*, December, 1939, pages 463–465, 1 illus., 1 table.

The Junkers Petrol Injection Engine. Direct gasoline-injection system and two-speed supercharger of the Junkers Jumo 211A twelve-cylinder inverted engines, which powered the Heinkel He.111K bomber shot down in Scotland, are described in great detail with many photographs and drawings of parts. Injection and supercharging system simply comprises a supercharger which forces pure air into the cylinders in a volume governed by the impeller whether in low or high gear and by the throttle setting. Pressure of air or boost, automatically controls the delivery of gasoline into the cylinders, and thus the fuel-air ratio for combustion is maintained automatically. Engine idles and runs well at various throttle openings under test, comparable with performance of normal supercharged engines fitted with carburetors. Water is employed for engine cooling with a 40 per cent content of Glycol as an antifreeze agent. A single pump at the rear of the engine circulates water through the cylinder jackets from a retractable radiator. Fuel used was 87 octane with lead content of 4.4 c.c/Imperial gallon.

Each combustion chamber has its own injector and is fed with fuel at approximately 73 lb. pressure from one of the plungers in a twelve-plunger pump unit located below the engine between the main cylinder banks. Injectors and spark plugs are extremely inaccessible. Injector screws directly into the combustion chamber in the same manner as a spark plug but a special construction is used in order that the fuel-feed pipe may be set in position radially without bending the pipe.

Supercharger is driven by a two-speed gear with clutches and a layshaft rotated by a bevel drive from the rear end of the crankshaft. No diffuser is employed for the impeller but a plain volute casing of comparatively small overall dimensions conducts air to the main induction pipe. Impeller is a hollow unit with box-form orifices for discharge of air under centrifugal force into the volute casing.

Rated engine horsepower 1050 at 2300 crankshaft r.p.m. at 14,000 ft. Bore 150 mm. Stroke 165 mm. Total capacity 35 liters. Weight with starter and generator 1525 lb. One of the engines has been repaired and is in full operation on the test bench at the Rolls-Royce plant. *Flight*, January 18, 1940, pages 46–50, 15 illus.

Aircraft Radio

A Simplified Approach to Frequency Modulation. H. W. Roberts. Advent of frequency modulation portends a fundamental basic change in the entire radio industry. Outstanding advantages claimed for frequency modulation over amplitude modulation are discussed, including: high fidelity; freedom from noise and from inter-station interference; low power; low weight; and low cost. Disadvantages in regard to frequency requirements are considered. Just what frequency modulation is is explained. To be continued. *Aero Digest*, February, 1940, pages 106, 109, 2 illus.

Book Review

Can America Prevent Frightfulness From the Air? by J. M. SPAIGHT; John Lane The Bodley Head, London, 1939; 71 pages, 2s.6d.

The author of this queer study is a careful student of air power. An odd trait in some Englishmen is their propensity for telling others how they should act, or at least they show great condescension if any course does not parallel that which they feel is correct.

Mr. Spaight has seized upon two statements by ex-President Hoover, who protested against the bombing of women and children and proposed that President Roosevelt sound a similar warning to the belligerents. Mr. Spaight believes that if these atrocities were committed after such a warning that the result would be an irresistible demand for the United States to enter the war.

Of course, the book was written before the war started and the author admits that "dips into the future are seldom lucky dips."

The book is an excellent example of brilliantly written foresight that became ridiculous as hindsight.